# THE SOUTH WALES INSTITUTE OF ENGINEERS.

[EMBRACING THE COALFIELDS OF SOUTH WALES AND MONMOUTHSHIRE, THE FOREST OF DEAN, GLOUCESTERSHIRE AND SOMERSETSHIRE.]

FOUNDED 1857—INCORPORATED BY ROYAL CHARTER, 1881.

# PROCEEDINGS.

## VOL. XXXVI.

THE SIXTY-THIRD SESSION.
1920.

EDITED BY THE SECRETARY.

PUBLISHED BY THE INSTITUTE, PARK PLACE, CARDIFF.

PRINTED BY
SPOTTISWOODE, BALLANTYNE & CO. LTD., LONDON, COLCHESTER AND ETON.

1921.

# CONTENTS OF PROCEEDINGS.

## VOLUME XXXVI.

### February 19, 1920, to December 16, 1920.

(Comprising Parts 1 and 2.)

No. 1. Volume XXXVI., issued July 16, 1920, price 10s.



No. 2. Volume XXXVI., issued January 21, 1921, price 10s.

# PAST PRESIDENTS
OF THE
# SOUTH WALES INSTITUTE OF ENGINEERS.
## 1920.

| | Sessions | |
|---|---|---|
| Menelaus, William, M.Inst.C.E. ... | 1857–58 ; 1864–65 ... | (Deceased) |
| Rogers, Ebenezer ... ... ... | 1858–59 ... ... | (Deceased) |
| Clark, William Southern ... ... | 1859–60 ... ... | (Deceased) |
| Brough, Lionel ... ... ... | 1860–61 ... ... | (Deceased) |
| Adams, William, A.M.Inst.C.E. ... | 1861–62 ... ... | (Deceased) |
| Evans, Thomas ... ... ... | 1862–63 ... ... | (Deceased) |
| Basset, Alexander, M.Inst.C.E. ... | 1863–64 ... ... | (Deceased) |
| Martin, George ... ... ... | 1865–66 ; 1866–67 ... | (Deceased) |
| Bedlington, Richard ... ... | 1867–68 ; 1868–69 ... | (Deceased) |
| Lewis, Sir William Thomas, Bart., M.Inst.C.E. (afterwards Lord Merthyr of Senghenydd), G.C.V.O. | 1869–70 ; 1870–71 & 1889–90 ; 1890–91 | (Deceased) |
| Steel, T. Dyne, M.Inst.C.E. ... | 1871–72 ; 1872–73 ... | (Deceased) |
| Brown, Thomas Forster, M.Inst.C.E. | 1873–74 ; 1874–75 & 1891–92 ; 1892–93 | (Deceased) |
| Brogden, James, F.G.S. ... ... | 1875–76 ; 1876–77 ... | (Deceased) |
| Laybourne, Richard ... ... | 1877–78 ; 1878–79 ... | (Deceased) |
| McMurtrie, James, F.G.S. ... | 1879–80 ; 1880–81 ... | (Deceased) |
| Williams, Edward, M.Inst.C.E. ... | 1881–82 ; 1882–83 ... | (Deceased) |
| Colquhoun, James ... ... ... | 1883–84 ; 1884–85 ... | (Deceased) |
| Hood, Archibald ... ... ... | 1885–86 ; 1886–87 ... | (Deceased) |
| Martin, Edward Pritchard, M.Inst. C.E. ... ... ... ... | 1887–88 ; 1888–89 ... | (Deceased) |
| Stevens, Arthur J., M.I.Mech.E. | 1893–94 ; 1894–95 | |
| Martin, Henry William, M.Inst.C.E. | 1895–96 ; 1896–97 | |
| Jordan, Henry Keyes, D.Sc., F.G.S. | 1897–98 ; 1898–99 | |
| Evens, Thomas, M.Inst.C.E. ... | 1899–00 ; 1900–01 | |
| Riches, T. Hurry, M.Inst.C.E. ... | 1901–02 ; 1902–03 ... | (Deceased) |
| Hann, Edmund Mills, M.Inst.C.E. | 1903–04 ; 1904–05 | |
| Deakin, Thos. Hedges, M.Inst.C.E. | 1905–06 ; 1906–07 | |
| Wight, William Dundas ... ... | 1907–08 ; 1908–09 & July 1911 to Dec. 1911 | |
| Rees, Ithel Treharne, M.Inst.C.E. | 1909–10 ; 1910 to July 1911 ... | (Deceased) |
| Galloway, W., D.Sc., F.G.S., F.I.D. | 1912 | |
| Elliott, A. C., D.Sc., M.Inst.C.E. | 1913 ... ... | (Deceased) |
| Atkinson, Sir W. N., LL.D. ... | 1913 (May 22 to Dec. 31, 1913) | |
| Wales, Henry T. ... ... ... | 1914 | |
| Griffiths, E. H., M.A., F.R.S. ... | 1915 | |
| Stewart, Wm. ... ... ... | 1916 | |
| Bramwell, Hugh, O.B.E. ... ... | 1917 | |
| Tallis, John Fox ... ... ... | 1918 | |
| Dawson, Edward, M.I.Mech.E. ... | 1919 | |

# THE SOUTH WALES INSTITUTE OF ENGINEERS.

## LIST OF OFFICE-BEARERS FOR SESSION 1921.

*President.*

| | |
|---|---|
| Lewis, J. Dyer ... ... ... ... ... | Session 1920. |

*Past Presidents.*

| | Sessions |
|---|---|
| Stevens, Arthur J., M.I.Mech.E. ... ... | 1893–94, 1894–95. |
| Martin, Henry W., M.Inst.C.E. ... ... ... | 1895–96, 1896–97. |
| Jordan, Henry K., D.Sc., F.G.S.... ... ... | 1897–98, 1898–99. |
| Evens, Thomas, M.Inst.C.E. ... ... ... | 1899–00, 1900–01. |
| Hann, E. M., M.Inst.C.E. ... ... ... ... | 1903–04, 1904–05. |
| Deakin, T. H., M.Inst.C.E. ... ... ... | 1905–06, 1906–07. |
| Wight, Wm. D. ... ... ... ... ... | 1907–08, 1908–09 & July to Dec. 1911. |
| Galloway, W., D.Sc., F.G.S., F.I.D. ... ... | 1912. |
| Wales, Henry T. ... ... ... ... ... | 1914. |
| Stewart, Wm. ... ... ... ... ... | 1916. |
| Bramwell, Hugh, O.B.E. ... ... ... | 1917. |
| Tallis, John Fox ... ... ... ... ... | 1918. |
| Dawson, Edward, M.I.Mech.E. ... ... ... | 1919. |

*Vice-Presidents.*

| | |
|---|---|
| Brown, W. Forster, M.Inst.C.E. ... ... | Cardiff. |
| Roberts, David E., M.Inst.C.E. ... ... ... | Cardiff. |
| Johnson, Wm. ... ... ... ... ... | Bridgend. |
| Vachell, Theodore, A.M.Inst.C.E. ... ... | Newport. |
| Chamen, W. A., M.I.E.E. ... ... ... ... | Cardiff. |
| Hood, W. W. ... ... ... ... ... | Cardiff. |

*Members of Council.*

| | |
|---|---|
| Knox, George, F.G.S., M.I.M.E. ... ... | Radyr. |
| Davies, J. C. ... ... ... ... ... | Gowerton. |
| Hannah, David ... ... ... ... ... | Penarth. |
| Johnson, T. Allan ... ... ... ... | Cardiff. |
| Bacon, Frederic, M.A., M.I.E.E. ... ... | Cardiff. |
| Sugden, Thomas, Wh.Sc., M.I.Mech.E. ... ... | London. |
| Jones, Howell R. ... ... ... ... | Dowlais. |
| Gilbertson, Francis W. ... ... ... | Pontardawe. |
| O'Connor, W., F.G.S. ... ... ... ... | Argoed, near Newport. |
| Davison, J. W. ... ... ... ... ... | Pontypridd. |
| Llewelyn, Sir Leonard W., K.B.E. ... ... | Newport, Mon. |
| Thomas, Trevor F., A.M.Inst.C.E. ... ... | Whitchurch, Glam. |
| Nicholas, Benjamin ... ... ... ... | Pontypool. |
| Thomas, Hubert Spence ... ... ... ... | Whitchurch, Glam. |
| Jacob, F. Llewellin ... ... ... ... | Ferndale. |
| Hutchinson, J. W. ... ... ... ... | Tondu. |
| Seyler, C. A., B.Sc. ... ... ... ... | Swansea. |
| Hann, E. L.... ... ... ... ... | Aberdare. |

*Secretary.*

| | |
|---|---|
| Price, Martin ... ... ... ... ... | Institute Buildings, Park Place, Cardiff. |

*Auditors.*

| | |
|---|---|
| McDonald, W., F.C.A., & Rees ... ... ... | Cardiff. |

*Treasurer.*

| | |
|---|---|
| The Manager, Lloyds Bank, Limited ... ... | Cardiff. |

*Solicitors.*

| | |
|---|---|
| Kenshole & Prosser ... ... ... ... | Aberdare. |

HOLDERS OF

# THE PRESIDENT'S GOLD MEDAL AND CERTIFICATE.

**Established in 1904, and to be awarded—in the discretion of the Council—for the best Papers read in each Presidential term.**

1904.

THE FIRST GOLD MEDAL

WAS AWARDED TO

Mr. Henry K. Jordan, F.G.S.

Paper, "The South Trough of the Coal Field, East Glamorgan.

1908.

THE GOLD MEDAL

WAS AWARDED TO

Mr. Edmund Mills Hann, M.Inst.C.E.

Paper, "A Recent Plant for the Utilisation of Small Coal."

1910.

THE GOLD MEDAL

WAS AWARDED TO

Mr. Hugh Bramwell.

Paper "Re-sinking and Re-equipping the Great Western Colliery Company's Maritime Pit."

1912.

THE GOLD MEDAL

WAS AWARDED TO

Mr. George G. Hann.

Paper, "Sinking and Equipping the Penallta Colliery."

# THE INSTITUTE GOLD MEDAL.

**In 1917 by Resolution of Council the name of the Medal, "The President's Gold Medal," was changed to that of "The Institute Gold Medal."**

1917.

THE GOLD MEDAL

WAS AWARDED TO

Mr. George Douglas Budge.

Paper, "Stone Dusting in Steam Coal Collieries."

# LEWIS PRIZE.

**Founded in 1895 by the late LORD MERTHYR of SENGHENYDD (Past-President), K.C.V.O., M.Inst.C.E., for the best Papers on subjects connected with Practical Mining and Practical Engineering, including Metallurgy.**

1898.—A First Prize was awarded to Mr. E. H. Thomas for his Paper on "Haulage," and a Second Prize to Mr. G. E. J. McMurtrie for his Paper on "Sinking."

1900.—A First Prize was awarded to Mr. S. A. Everett, and a Second Prize to Mr. E. H. Thomas, for Papers on "Colliery Surface Arrangements."

1901.—A Second Prize was awarded to Mr. Ralph Hawtrey, a Student, for his Paper "The Best and Most Economical System of Working Seams of Coal of Moderate Inclination in South Wales."

1904.—A First Prize was awarded to Mr. H. D. B. How, A.M.I.E.E. for his Paper "Coal Winding Machinery."

1905.—A First Prize was awarded to Mr. W. Waplington for his Paper "Description and Design of the Best Arrangements of Equipment of the Bottom, with a Radius of 400 yards, of a Pair of Pits to be Upcast and Downcast Respectively."

1906.—A Second Prize was awarded to Mr. George Roblings for his Paper "Separation (Sizing) and Washing of Coal."

1907.—A First Prize was awarded to Mr. Daniel Davies, and a Second Prize to Mr. Gath J. Fisher, for their Papers on "Pumping and Drainage," and also on "Sinking Shafts."

1908.—A First Prize was awarded to Mr. H. A. Staples, a Second Prize to Mr. George Roblings, and a Third Special Prize to Mr. M. D. Williams, for their Papers "As to the Best Methods of Working Seams of Coal in Steep Measures."

1909.—A First Prize was awarded to Mr. William Trimmer, and a Second Prize to Mr. C. W. Jordan, A.M.I.Mech.E., for their Papers on "General Lay-out and Equipment of a Complete Set of Engineering Shops for a Modern Colliery with an Output of about 2,000 tons per day."

1910.—A First Prize was awarded to Mr. George Roblings, and a Second Prize to Mr. Noah T. Williams, for their Papers on "Washing and Sorting of Small Coal."

1913.—Special Prize awarded Mr. Will Gregson for his Paper "The Most Approved Methods of Hauling the Coal from the Working Faces to the Pit Bottom."

1914.—Special Prizes awarded Messrs. J. Williams and S. R. Cound for their Papers on "How to Improve Welsh Tinplate Rolling-mill Practice."

1918.—A First Prize was awarded to Mr. W. T. Lane, and a Second to Mr. W. H. Casmey, for their Papers on "Fuel Economy in Power Production (or Utilisation of Waste Heat)."

1920.—A First Prize of £20 was awarded to Mr. R. C. Morgan for his Paper on "Causes of Subsidences and the best Safeguards for their Prevention."

# SPENCE THOMAS SCHOLARSHIP.

*(Founded in 1918 by Mr. H. Spence Thomas for the encouragement of the Members of the Associations of Students of the Institute.)*

The interest on £1,000 5 per cent. War Loan Stock shall be devoted to the Scholarship.

The Holder of the Scholarship must be a Member of one of the Students' Associations of the Institute, and must be a Student at one of the Colleges, Schools, or Institutions recognised as suitable by the Council of the Institute.

The Council of the Institute shall award the Scholarship upon Reports presented for its consideration by the Heads of any of the above Colleges, Schools, or Institutions, on the completion of one year's study by any student.

The College, School, or Institution shall present an annual Report to the Council on the work and progress of the Scholar to whom the Scholarship shall have been awarded, and the Council retains the right of withholding or cancelling the Scholarship, if in its opinion the progress of the Scholar is unsatisfactory.

In the award of the Scholarship the professional knowledge and practical experience of the candidate shall be taken into consideration.

No candidate will be elected to the Scholarship until he has satisfied the Council that his physical condition is satisfactory.

The Scholarship shall be awarded for a term of one, two, or more years in the discretion of the Council. The Scholar to briefly report at the end of each year upon the work accomplished.

The Council reserves the right to withhold the Scholarship if no candidate of sufficient merit presents himself.

1919–1921. The Spence Thomas Scholarship of £50 per annum was awarded to Mr. William John Gilbert, Nantyglo, for a period of three years, tenable at the School of Mines, Treforest.

## INSTITUTE SCHOLARSHIP IN ENGINEERING.

***Granted by the Council in 1904, and tenable for three years at the University College of South Wales and Monmouthshire.***

1904.—An EXHIBITION of £60, awarded to Mr. Ernest Clarke Stroud, Chatham.

1905-08.—A SCHOLARSHIP of £70 per annum, awarded to Mr. E.C. Stroud.

1908-11.—A SCHOLARSHIP of £70 per annum, awarded to Mr. Ivor Richard Cox, Cardiff.

1912.—An EXHIBITION of £60, awarded to Mr. Victor John French, Chatham.

1912-15.—A SCHOLARSHIP of £70 per annum, awarded to Mr. Victor John French.

1915-18.—A SCHOLARSHIP of £70 per annum, awarded to Mr. E. W. H. Knight, Devonport,

Note.—Mr. Knight was unable to take up the Scholarship he had won, and an honorarium of £10 was granted him by the Council, also a Certificate to the effect that he had won the Scholarship.

1919-21.—An EXHIBITION of £13 (plus a bonus of £15) per annum, awarded to Mr. E. G. Davies, Cardiff. (Won in 1915.)

1919-21.—A SCHOLARSHIP of £70 per annum, plus a bonus of £15 per annum, awarded to Mr. Myrddin David, County School, Porth, and

1919-20.—An EXHIBITION of £30 per annum for two years, awarded to Mr. J. Selwyn Caswell, Ebbw Vale.

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### ADVERTISEMENT.

The Editor of these Proceedings is directed to make it known that the Authors alone are responsible for the facts and opinions contained in their respective Papers, and the individual speakers for their statements made in Discussion.

# DIRECTIONS TO BINDER.

## VOLUME XXXVI.

COMPRISES PARTS 1 and 2.

ORDER OF BINDING.

FIRST :—Title Page, Contents of Volume, etc., pages (i) to (x) inclusive.

SECOND :—Photograph of President (Mr. J. Dyer Lewis), to face page 1. (See Part 1.)

THIRD :—Proceedings, pages 1 to 574 inclusive.

FOURTH :—Index to Volume xxxvi., pages 575 to 585 inclusive.

ISSUED JULY 16th, 1920.

VOL. XXXVI.] [No. 1.

# PROCEEDINGS

OF

# THE SOUTH WALES INSTITUTE OF ENGINEERS.

[EMBRACING THE COAL-FIELDS OF SOUTH WALES AND MONMOUTHSHIRE, THE FOREST OF DEAN, GLOUCESTERSHIRE, AND SOMERSETSHIRE.]

FOUNDED 1857—INCORPORATED BY ROYAL CHARTER 1881.

ORDINARY GENERAL MEETING, CARDIFF, FEBRUARY 19TH; SPECIAL JOINT MEETING WITH THE SOCIETY OF CHEMICAL INDUSTRY, CARDIFF, MARCH 3RD; 62ND ANNUAL GENERAL MEETING, MARCH 26TH, CARDIFF; SPECIAL GENERAL MEETING, CONISHEAD PRIORY, JUNE 8TH; AND MEETING OF CARDIFF UNIVERSITY COLLEGE ASSOCIATION OF STUDENTS, MARCH 4TH, 1920.

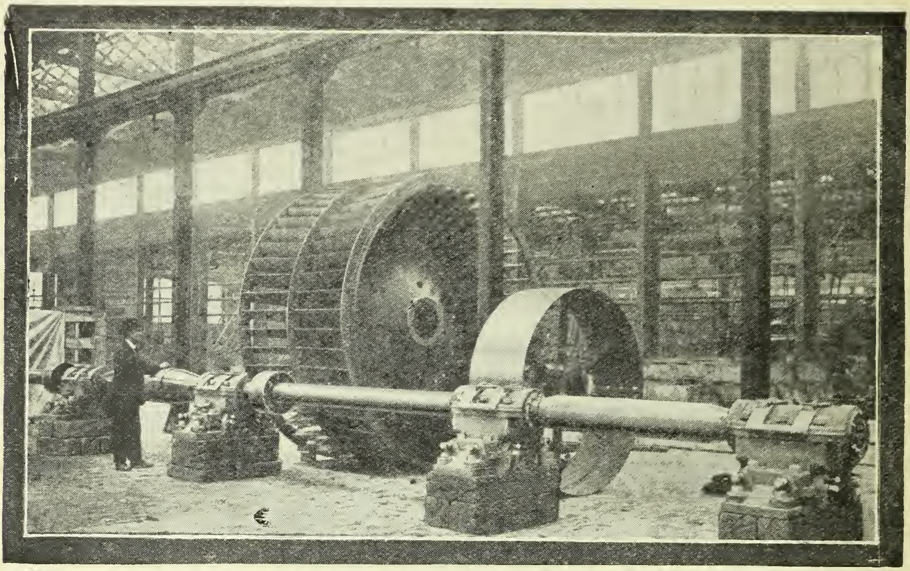
EDITED BY THE SECRETARY


PUBLISHED BY THE INSTITUTE, PARK PLACE, CARDIFF.

PRINTED BY SPOTTISWOODE, BALLANTYNE & Co. LTD., LONDON, COLCHESTER & ETON

1920.

*Price* 10/-.



# PAST PRESIDENTS

OF THE

# SOUTH WALES INSTITUTE OF ENGINEERS.

## 1920.

| | SESSIONS | |
|---|---|---|
| Menelaus, William, M.Inst.C.E. ... | 1857–58 ; 1864–65 ... | (Deceased) |
| Rogers, Ebenezer ... ... ... | 1858–59 ... ... | (Deceased) |
| Clark, William Southern ... ... | 1859–60 ... ... | (Deceased) |
| Brough, Lionel ... ... ... | 1860–61 ... ... | (Deceased) |
| Adams, William, A.M.Inst.C.E. ... | 1861–62 ... ... | (Deceased) |
| Evans, Thomas ... ... ... | 1862–63 ... ... | (Deceased) |
| Basset, Alexander, M.Inst.C.E. ... | 1863–64 ... ... | (Deceased) |
| Martin, George ... ... ... | 1865–66 ; 1866–67 ... | (Deceased) |
| Bedlington, Richard ... ... | 1867–68 ; 1868–69 ... | (Deceased) |
| Lewis, Sir William Thomas, Bart., M.Inst.C.E. (afterwards Lord Merthyr of Senghenydd), G.C.V.O. | 1869–70 ; 1870–71 & 1889–90 ; 1890–91 | (Deceased) |
| Steel, T. Dyne, M.Inst.C.E. ... | 1871–72 ; 1872–73 ... | (Deceased) |
| Brown, Thomas Forster, M.Inst.C.E. | 1873–74 ; 1874–75 & 1891–92 ; 1892–93 | (Deceased) |
| Brogden, James, F.G.S. ... ... | 1875–76 ; 1876–77 ... | (Deceased) |
| Laybourne, Richard ... ... | 1877–78 ; 1878–79 ... | (Deceased) |
| McMurtrie, James, F.G.S. ... | 1879–80 ; 1880–81 ... | (Deceased) |
| Williams, Edward, M.Inst.C.E. ... | 1881–82 ; 1882–83 ... | (Deceased) |
| Colquhoun, James ... ... ... | 1883–84 ; 1884–85 ... | (Deceased) |
| Hood, Archibald ... ... ... | 1885–86 ; 1886–87 ... | (Deceased) |
| Martin, Edward Pritchard, M.Inst. C.E. ... ... ... ... | 1887–88 ; 1888–89 ... | (Deceased) |
| Stevens, Arthur J., M.I.Mech.E. | 1893–94 ; 1894–95 | |
| Martin, Henry William, M.Inst.C.E. | 1895–96 ; 1896–97 | |
| Jordan, Henry Keyes, D.Sc., F.G.S. | 1897–98 ; 1898–99 | |
| Evens, Thomas, M.Inst.C.E. ... | 1899–00 ; 1900–01 | |
| Riches, T. Hurry, M.Inst.C.E. ... | 1901–02 ; 1902–03 ... | (Deceased) |
| Hann, Edmund Mills, M.Inst.C.E. | 1903–04 ; 1904–05 | |
| Deakin, Thos. Hedges, M.Inst.C.E. | 1905–06 ; 1906–07 | |
| Wight, William Dundas ... ... | 1907–08 ; 1908–09 & July 1911 to Dec. 1911 | |
| Rees, Ithel Treharne, M.Inst.C.E. | 1909–10 ; 1910 to July 1911 ... | (Deceased) |
| Galloway, W., D.Sc., F.G.S., F.I.D. | 1912 | |
| Elliott, A. C., D.Sc., M.Inst.C.E. | 1913 ... ... | (Deceased) |
| Atkinson, Sir W. N., LL.D. ... | 1913 (May 22 to Dec. 31, 1913) | |
| Wales, Henry T. ... ... ... | 1914 | |
| Griffiths, E. H., M.A., F.R.S. ... | 1915 | |
| Stewart, Wm. ... ... ... | 1916 | |
| Bramwell, Hugh, O.B.E. ... ... | 1917 | |
| Tallis, John Fox ... ... ... | 1918 | |
| Dawson, Edward, M.I.Mech.E. ... | 1919 | |

# THE SOUTH WALES INSTITUTE OF ENGINEERS.

## LIST OF OFFICE-BEARERS FOR SESSION 1920.

*President.*

| | |
|---|---|
| Lewis, J. Dyer ... ... ... ... ... | Session 1920. |

*Past Presidents.*

| | Sessions |
|---|---|
| Stevens, Arthur J., M.I.Mech.E. ... ... | 1893–94, 1894–95. |
| Martin, Henry W., M.Inst.C.E. ... ... ... | 1895–96, 1896–97. |
| Jordan, Henry K., D.Sc., F.G.S.... ... ... | 1897–98, 1898–99. |
| Evens, Thomas, M.Inst.C.E. ... ... ... | 1899–00, 1900–01. |
| Hann, E. M., M.Inst.C.E. ... ... ... ... | 1903–04, 1904–05. |
| Deakin, T. H., M.Inst.C.E. ... ... ... | 1905–06, 1906–07. |
| Wight, Wm. D. ... ... ... ... ... | 1907–08, 1908–09 & July to Dec. 1911. |
| Galloway, W., D.Sc., F.G.S., F.I.D. ... ... | 1912. |
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| Griffiths, E. H., M.A., F.R.S. ... ... ... | 1915. |
| Stewart, Wm. ... ... ... ... ... | 1916. |
| Bramwell, Hugh, O.B.E. ... ... ... | 1917. |
| Tallis, John Fox ... ... ... ... ... | 1918. |
| Dawson, Edward, M.I.Mech.E. ... ... ... | 1919. |

*Vice-Presidents.*

| | |
|---|---|
| Brown, W. Forster, M.Inst.C.E. ... ... | Cardiff. |
| Roberts, David E., M.Inst.C.E. ... ... ... | Cardiff. |
| Johnson, Wm. ... ... ... ... ... | Bridgend. |
| Vachell, Theodore, A.M.Inst.C.E. ... ... | Newport. |
| Chamen, W. A., M.I.E.E. ... ... ... ... | Cardiff. |
| Hood, W. W. ... ... ... ... ... | Cardiff. |

*Members of Council.*

| | |
|---|---|
| Knox, George, F.G.S., M.I.M.E. ... ... | Radyr. |
| Davies, J. C. ... ... ... ... ... | Gowerton. |
| Hannah, David ... ... ... ... ... | Penarth. |
| Johnson, T. Allan ... ... ... ... | Cardiff. |
| Bacon, Frederic, M.A., M.I.E.E. ... ... | Cardiff. |
| Sugden, Thomas, Wh.Sc., M.I.Mech.E. ... ... | London. |
| Jones, Howell R. ... ... ... ... | Dowlais. |
| Gilbertson, Francis W. ... ... ... | Pontardawe. |
| O'Connor, W., F.G.S. ... ... ... ... | Argoed, near Newport. |
| Davison, J. W. ... ... ... ... ... | Pontypridd, |
| Llewelyn, Sir Leonard W., K.B.E. ... ... | Newport, Mon. |
| Thomas, Trevor F., A.M.Inst.C.E. ... ... | Whitchurch, Glam. |
| Nicholas, Benjamin ... ... ... ... | Pontypool. |
| Thomas, Hubert Spence... ... ... ... | Whitchurch, Glam. |
| Jacob, F. Llewellin ... ... ... ... | Ferndale. |
| Hutchinson, J. W. ... ... ... ... | Tondu. |
| Seyler, C. A., B.Sc. ... ... ... ... | Swansea. |
| Hann, E. L. ... ... ... ... ... | Aberdare. |

*Secretary.*

| | |
|---|---|
| Price, Martin ... ... ... ... ... | Institute Buildings, Park Place, Cardiff. |

*Auditors.*

| | |
|---|---|
| McDonald, W., F.C.A., & Rees ... ... ... | Cardiff. |

*Treasurer.*

| | |
|---|---|
| The Manager, Lloyds Bank, Limited ... ... | Cardiff. |

*Solicitors.*

| | |
|---|---|
| Kenshole & Prosser ... ... ... ... | Aberdare. |

HOLDERS OF

# THE PRESIDENT'S GOLD MEDAL AND CERTIFICATE.

**Established in 1904, and to be awarded—in the discretion of the Council—for the best Papers read in each Presidential term.**

1904.

THE FIRST GOLD MEDAL

WAS AWARDED TO

Mr. HENRY K. JORDAN, F.G.S.

PAPER, "THE SOUTH TROUGH OF THE COAL FIELD, EAST GLAMORGAN."

---

1908.

THE GOLD MEDAL

WAS AWARDED TO

Mr. EDMUND MILLS HANN, M.Inst.C.E.

PAPER, "A RECENT PLANT FOR THE UTILISATION OF SMALL COAL."

---

1910.

THE GOLD MEDAL

WAS AWARDED TO

Mr. HUGH BRAMWELL.

PAPER "RE-SINKING AND RE-EQUIPPING THE GREAT WESTERN COLLIERY COMPANY'S MARITIME PIT."

---

1912.

THE GOLD MEDAL

WAS AWARDED TO

Mr. GEORGE G. HANN.

PAPER, "SINKING AND EQUIPPING THE PENALLTA COLLIERY."

---

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1905.—A First Prize was awarded to Mr. W. Waplington for his Paper "Description and Design of the Best Arrangements of Equipment of the Bottom, with a Radius of 400 yards, of a Pair of Pits to be Upcast and Downcast Respectively."

1906.—A Second Prize was awarded to Mr. George Roblings for his Paper "Separation (Sizing) and Washing of Coal."

1907.—A First Prize was awarded to Mr. Daniel Davies, and a Second Prize to Mr. Gath J. Fisher, for their Papers on "Pumping and Drainage," and also on "Sinking Shafts."

1908.—A First Prize was awarded to Mr. H. A. Staples, a Second Prize to Mr. George Roblings, and a Third Special Prize to Mr. M. D. Williams, for their Papers "As to the Best Methods of Working Seams of Coal in Steep Measures."

1909.—A First Prize was awarded to Mr. William Trimmer, and a Second Prize to Mr. C. W. Jordan, A.M.I.Mech.E., for their Papers on "General Lay-out and Equipment of a Complete Set of Engineering Shops for a Modern Colliery with an Output of about 2,000 tons per day."

1910.—A First Prize was awarded to Mr. George Roblings, and a Second Prize to Mr. Noah T. Williams, for their Papers on "Washing and Sorting of Small Coal."

1913.—Special Prize awarded Mr. Will Gregson for his Paper "The Most Approved Methods of Hauling the Coal from the Working Faces to the Pit Bottom."

1914.—Special Prizes awarded Messrs. J. Williams and S. R. Cound for their Papers on "How to Improve Welsh Tinplate Rolling-mill Practice."

1918.—A First Prize was awarded to Mr. W. T. Lane, and a Second to Mr. W. H. Casmey, for their Papers on "Fuel Economy in Power Production (or Utilisation of Waste Heat)."

1920.—Subject selected for Competition :—"Causes of Subsidences and the Best Safeguards for their Prevention." 1st Prize £20, 2nd Prize £10.

## INSTITUTE SCHOLARSHIP IN ENGINEERING.

***Granted by the Council in 1904, and tenable for three years at the University College of South Wales and Monmouthshire.***

1904.—An EXHIBITION of £60, awarded to Mr. ERNEST CLARKE STROUD, Chatham.

1905-08.—A SCHOLARSHIP of £70 per annum, awarded to Mr. E.C. STROUD.

1908-11.—A SCHOLARSHIP of £70 per annum, awarded to Mr. IVOR RICHARD COX, Cardiff.

1912.—An EXHIBITION of £60, awarded to Mr. VICTOR JOHN FRENCH, Chatham.

1912-15.—A SCHOLARSHIP of £70 per annum, awarded to Mr. VICTOR JOHN FRENCH.

1915-18.—A SCHOLARSHIP of £70 per annum, awarded to Mr. E. W. H. KNIGHT, Devonport.

NOTE.—Mr. Knight was unable to take up the Scholarship he had won, and an honorarium of £10 was granted him by the Council, also a Certificate to the effect that he had won the Scholarship.

1919-21.—An EXHIBITION of £13 (plus a bonus of £15) per annum, awarded to Mr. E. G. DAVIES, Cardiff. (Won in 1915.)

1919-21.—A SCHOLARSHIP of £70 per annum, plus a bonus of £15 per annum, awarded to Mr. MYRDDIN DAVID, County School, Porth, and

1919-20.—An EXHIBITION of £30 per annum for two years, awarded to Mr. J. SELWYN CASWELL, Ebbw Vale.

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# NOTICES.

The EDITOR of these Proceedings is directed to make it known that the Authors alone are responsible for the facts and opinions contained in their respective Papers, and the individual speakers for their statements made in discussion.



## PROCEEDINGS.

Back Numbers of the Proceedings have now been bound, from Vol. I. inclusive, in Volumes, in strong Duro-Flexile Cloth, and may be obtained from the Secretary at £1. 1s. per volume, or separate back numbers can be had at the various prices marked on the covers.

## CHANGE OF RESIDENCE.

The SECRETARY would be obliged by Members notifying to him any alteration in their addresses at the earliest date.

## INSTITUTE BUILDING.

The INSTITUTE, Park Place, Cardiff, is open for the use of Members on Week-days from 10 A.M. to 5 P.M.

The NEW LIBRARY is now open for the use of Members, and the technical journals and other periodicals will be found on the tables in that room, instead of in the Council Chamber.

## INSTITUTE ROOM AT SWANSEA.

A Room on the ground floor of the Metal Exchange, Swansea, is open for the use of Members on week-days from 10 A.M. to 7 P.M.

# SPENCE THOMAS SCHOLARSHIP.

***(Founded in 1918 by Mr. H. Spence Thomas for the encouragement of the Members of the Associations of Students of the Institute.)***

The interest on £1,000 5 per cent. War Loan Stock shall be devoted to the Scholarship.

The Holder of the Scholarship must be a Member of one of the Students' Associations of the Institute, and must be a Student at one of the Colleges, Schools, or Institutions recognised as suitable by the Council of the Institute.

The Council of the Institute shall award the Scholarship upon Reports presented for its consideration by the Heads of any of the above Colleges, Schools, or Institutions, on the completion of one year's study by any student.

The College, School, or Institution shall present an annual report to the Council on the work and progress of the Scholar to whom the Scholarship shall have been awarded, and the Council retains the right of withholding or cancelling the Scholarship, if in its opinion the progress of the Scholar is unsatisfactory.

In the award of the Scholarship the professional knowledge and practical experience of the candidate shall be taken into consideration.

No candidate will be elected to the Scholarship until he has satisfied the Council that his physical condition is satisfactory.

The Scholarship shall be awarded for a term of one, two, or more years in the discretion of the Council. The Scholar to briefly report at the end of each year upon the work accomplished.

The Council reserves the right to withhold the Scholarship if no candidate of sufficient merit presents himself.

1919–1921. The Spence Thomas Scholarship of £50 per annum was awarded to Mr. William John Gilbert, Nantyglo, for a period of three years, tenable at the School of Mines, Treforest.

# ADVERTISEMENTS.



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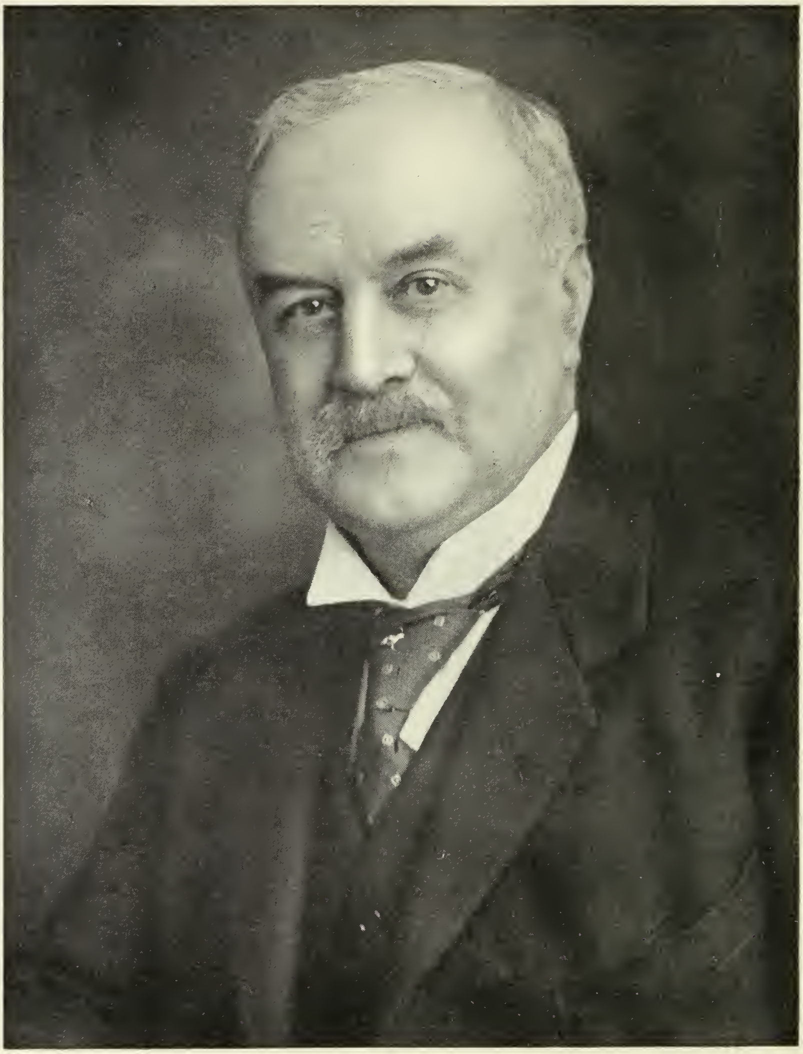
No. 1. VOLUME XXXVI., issued July 16th, 1920, price 10s.



*Elliott & Fry, Photographers, Baker Street, London.]*

MR. J. DYER LEWIS

President of the South Wales Institute of Engineers

SESSION 1920

# PROCEEDINGS.

## Ordinary General Meeting, Cardiff, February 19, 1920.

THE Ordinary General Meeting of the South Wales Institute of Engineers was held at the Institution, Cardiff, on Thursday, February 19, 1920.

The chair was taken, at the outset, by Mr. Edward Dawson, the retiring President.

The Minutes of the General Meeting of the Institute, held November 28, 1919, were read and confirmed.

The Minutes of the joint meeting of the South Wales Institute and the Chemical Industries Society, held at the Institution on November 27, 1919, were read and confirmed.

## Election of Members.

The following candidates for admission to the Institute were declared duly elected :

*As Members.*

| | |
|---|---|
| HALL, JAMES . . . . | Skewen, near Neath. |
| HUGHES, MORRIS . . . | Cardiff. |
| HUNT, LOUIS JOHN . . . | Bromley, Kent. |
| JONES, CHARLES GODFREY . . | Waunllwyd, Mon. |
| JONES, EDWARD CYRIL . . | Pontypridd. |
| MERCER, HORACE EDWARD . | Llanelly. |
| NAKAGAKI, NAOTO . . . | Kobe, Japan. |

| | |
|---|---|
| Roberts, Sidney Douglas . | Cardiff. |
| Sergeant, Frederick Sidney . | Neath Abbey, Neath. |
| Thomas, Gwilym Ewart Aeron | Coedglas, West Cross, S.O., Glam. |
| Williams, E. S. . . . | Hendrederwen, Abertridwr. |
| Wolff, Salomon . . . | Cardiff. |

*As Associate Member.*

| | |
|---|---|
| Edwards, Horace John . . | Swansea. |

*As Student.*

| | |
|---|---|
| Howells, Jenkin Owen . . | Gwauncaegurwen, Glam. |

## Admission of New Members.

The following gentlemen, who had been previously elected, signed the Roll Book and were admitted to the Institute :—

| | |
|---|---|
| Hunt, Louis John . . . | Bromley, Kent. |
| Sergeant, Frederick Sidney . | Neath Abbey. |

**The Retiring President.**

The Retiring President said the formal business being concluded, it was now his duty to announce that the Council had elected as his successor in the chair for the ensuing session, Mr. J. Dyer Lewis, a gentleman who was well known to them all. As they were aware, Mr. Dyer Lewis occupied a very important official position in the Coalfield, and it might be that his onerous professional work might, at times, interfere with his duties as President of the Institute, but they might rely upon him making every endeavour to be amongst them at their meetings and discharging the various duties appertaining to the honourable position to which they had called him. (Applause.) For his own part, he desired to thank them for the support and co-operation they had extended to him during his year of office. He desired especially to

The Retiring President.

acknowledge the assistance he had received from their very able Secretary, Mr. Martin Price. (Applause.) During the time Mr. Price had been Secretary of the Institute there was probably no member who had been more closely associated with him than he (Mr. Dawson) had been, by reason of his official position as Chairman of the House and Finance Committees, and he could cordially testify to his ever readiness to further the interests of the Institute which he had so much at heart. During the year 1919 there had been an increase of 191 in the membership of the Institute, which was largely due to the accession of students in the Engineering Society of the University College of South Wales and Monmouthshire. There were now 428 students attached to the Institute, many of whom, he hoped, would become full and useful members as they advanced in years and knowledge. It was to them that, in a large measure, they must look to carry on the Institute in the time to come. (Hear, hear.) Twelve months ago he was described as 'the Finance Member of the Institute.' As such he was pleased to be able to report that during his term of office their investments had increased by over £800, and that the Institute was in a sound financial position. At the same time, he wished to urge the importance of every member sending his annual subscription as promptly as possible, so that accounts might be regularly paid and the Secretary spared as much trouble and anxiety on that score as possible. With the observation that he thought some valuable papers had been contributed to the Transactions of the Institute, he need not say more about the year just passed. He had been much interested in the work attaching to the presidency, and he should always look back upon the time when they did him so much honour with feelings of pride and gratification. (Applause.) He had now to ask Mr. Dyer Lewis to take the chair.

The New President.

The New President was received with acclamation. He said his warmest thanks were due to the Council for having placed him in the highest position it was in the power of the Institute to bestow, and to attain which should be the laudable ambition of every member. He recognised that as the membership grew the work of the President must also increase year by year, and he trusted that it would be his privilege to meet all the demands which might be made upon him in the discharge of his new duties at the head of the Institute during the next twelve months. He could promise them to do his best. (Applause.) He need scarcely say it was very gratifying to him to occupy the presidency of one of the strongest learned societies in the country so far as membership was concerned. He appealed to members to make every effort to attend the meetings of the Institute. He knew that times were rather difficult, and that they had their own exacting professional duties to attend to, but presence at Institute meetings was always time well spent. During the past four or five years—the period of the war—they had not been able to have their usual attendances: these could not be expected: nor had they been able to hold any social functions. He attached importance to these; and it was most pleasing to learn from Mr. Dawson that he had £800 in hand to be spent this year on social gatherings. (Laughter.)

Mr. H. T. Wales.

Mr. H. T. Wales proposed a vote of thanks to Mr. Dawson for his services as President during the past year. He said Mr. Dawson had always been an enthusiastic member of the Institute. He had taken into his particular care the Institute's finances, which in the case of both public bodies and private individuals were of vital importance. He was a regular attendant at his committee meetings and at general meetings of the Institute over a long period of years, and they had also benefited by his ripe experience in all matters appertaining

to colliery engineering, especially on the mechanical side. He had had the pleasure of knowing Mr. Dawson for a longer time than he cared to remember, and had always felt the greatest admiration for the way in which he had carried on his profession of mechanical engineer in connection with collieries. He asked them to accord to the ex-President a hearty vote of thanks for his services as President, and he was sure they would concur with him that he had worthily upheld the best traditions of the distinguished position he had just vacated. (Applause.)

Mr. W. A. Chamen said it gave him great pleasure to second the vote of thanks proposed by Mr. Wales. He had been brought into frequent contact with Mr. Dawson for several years, especially in his capacity as Chairman of the House and Finance Committee, and he could bear personal testimony to the zeal and assiduity shown by the ex-President on behalf of the affairs of the Institute in transacting the important business of that Committee. (Applause.) **Mr. W. A. Chamen.**

The resolution was cordially adopted, and the ex-President, thanking members, said it was gratifying to know he had given satisfaction.

## The Presidential Address.

The President (Mr. J. Dyer Lewis) then delivered his inaugural address as follows :— **The President.**

This year will be remembered by future generations as the one in which peace was declared, after five years of the greatest war known to history, in which many millions of men were engaged in actual fighting, and millions more in preparing munitions for it to be carried on successfully.

Engineers were engaged in devising and perfecting guns of heavy calibre not known in previous wars. The consumption of shells even in a single battle was greater than in any

The President. other campaign. Chemists utilised their scientific knowledge in inventing new and more powerful explosives, and later in preparing huge quantities of poisonous gases. Intellect and science have therefore been wholly employed in the work of destruction of human life. Let us hope that such warfare will never occur again.

The South Wales coal-mining industry contributed 50,000 to 60,000 men. Mining engineers and officials, of whom several were members of this Institute, together with workmen, answered the call of their country, and many of them laid down their lives.

Miners were drafted from infantry battalions to form Tunnelling Companies during the year 1915 and the early part of 1916, and a special call for miners was made in colliery districts to form as many of these companies as possible; they were sent out with scarcely the knowledge necessary to fire a rifle, so urgent was the need of them. The Germans were the first to start mining systems and consequently were ahead of our men, who were therefore called upon to work their utmost in order to get level and ultimately ahead of the Germans. As a result our miners had attained superiority when the great mine attack at Messines was started, because they, with infinite caution and dogged determination, laid several thousand of pounds of one of the then most deadly explosives without the German Tunnelling Section having the slightest idea as to what was going to happen. Many an exciting story could be told by these brave men of their doings in the dangerous underground work which was their task in France, how quite suddenly they would strike the German galleries and wait and watch for the first man to come along. On one occasion, a German gallery was struck and our men fired their mine.

In the majority of cases the shafts and galleries were

timbered in the same way as our mines are timbered in this country. Of course, in some cases, timbering and mining were most difficult on account of the chalk and the amount of clay in the soil, and timbers in these cases were known to be sometimes only about 2 feet and less apart. In other cases also, water found its way into these galleries and a system of pumping had to be arranged: some mines merely had hand pumps supplied, as are to be found in ships; others had more elaborate pumps, driven by electric motors. Ventilation was also a difficult problem which had to be solved, because, as you are aware, no upcast and downcast shafts were possible. The most popular kind of ventilation was created by means of a fan driven electrically, which sucked out the air from the innermost faces quite successfully. **The President.**

A feature of special interest to mining engineers was the extensive use of rescue apparatus at the front, and in this particular those trained at the various Rescue Stations connected with coal-mines played prominent parts. Training stations some miles back from the line were equipped with a certain type of breathing apparatus well known in South Wales. Underground tunnels were made and practice of a severe character was carried on in fumes which were irrespirable. A great point was made of thorough physical training, military discipline, and regular systematic examination by medical men. The result was a fine body of men, who ran great risks in driving and charging tunnels often filled with most deadly gases. The use of certain explosives had to be discontinued in consequence of the fumes which they generated upon detonation. It has been stated that work with breathing apparatus which has received so much attention during recent years by mining engineers, and which in course of time will develop into real usefulness in our own disasters, has been of much service during the late war.

**The President.** It appears to me that some of the methods of training adopted might be applied to our Rescue Stations, such as discipline of a high order, thorough knowledge of and confidence in the apparatus in use, and the selection of men of the very best physique. This would tend to render our Rescue Stations more valuable in pit disasters.

### *Effect of the War on Mining.*

The period of the war was one of great difficulty to those responsible for the management of the mines. The loss of many officials, and a large number of the young and able workmen, who volunteered for active service, together with urgent requests for increased output of coal for naval and munition purposes, caused the agents and managers most anxious times. In addition to these difficulties it was practically impossible to obtain many essential appliances and stores. The Ministry of Munitions gave considerable assistance in procuring from manufacturers what was actually necessary in matters affecting the safety of the mines.

The importation of pitwood was so seriously reduced that it became imperative to make use of native timber; committees were formed by the Government and the coal-owners to allocate to such mines as had not private supplies the timber necessary to keep the collieries working. Those committees ultimately supplied the greater part of the wood used, and deserve the thanks of the country for the excellent results obtained. The timber was not always of the type supplied in normal times, but deaths from accidents due to falls of roof show a reduction for the years 1915 to 1917. In 1918 there was a slight increase, but in 1919 there was a considerable reduction. These facts are in favour of the use of home-grown pitwood, although complaints of the unsuitability of the timber were frequently received.

**The President.**

Development in existing mines and the sinking of new shafts were prohibited during the early stages of the war, but these Regulations were subsequently considerably relaxed as increased output of coal became necessary. Mines producing gas, and bituminous coals for manufacturing purposes, were especially allowed full development.

Notwithstanding these precautions the output gradually decreased owing to the absence of large numbers of the most able men who had been recruited, the difficulty in procuring tonnage for export, and irregularity in the attendance of the miners.

The great European war has left an indelible mark upon industrial workers generally. It is not confined to mining, and not to this country. It is world-wide, and has reached the aborigines of Africa. They all cry out for better conditions of life, better housing, and more leisure. Medical men agree that improved conditions of living will make for a better class of workman, and in dangerous occupations will tend to reduce accidents, by the increased mental vigour of the men in the detection of danger.

This new view of life taken by all workers alike cannot be ignored, and it behoves those who have the future of the country at heart to do all that is possible to relieve the situation.

It is claimed by all economists and politicians that the only way to reduce the present high prices paid for food, clothing, and all other articles necessary to maintain the population, is by increased production. It is therefore incumbent upon all workmen to do so, and for employers to provide all that is required in order that it can be done and maintained.

The output of coal from South Wales and Monmouthshire per person employed below ground has been gradually on the

The President. decrease since the year 1883, and is indicated in the following figures:

| Year. | Tons. | Year. | Tons. | Year. | Tons. |
|---|---|---|---|---|---|
| 1880 | 363 | 1893 | 301 | 1906 | 317 |
| 1881 | 361 | 1894 | 314 | 1907 | 309 |
| 1882 | 358 | 1895 | 307 | 1908 | 293 |
| 1883 | 368 | 1896 | 317 | 1909 | 289 |
| 1884 | 357 | 1897 | 331 | 1910 | 268 |
| 1885 | 333 | 1898 | 244[1] | 1911 | 266 |
| 1886 | 331 | 1899 | 356 | 1912 | 261 |
| 1887 | 350 | 1900 | 316 | 1913 | 286 |
| 1888 | 349 | 1901 | 307 | 1914 | 270 |
| 1889 | 330 | 1902 | 315 | 1915 | 297 |
| 1890 | 312 | 1903 | 311 | 1916 | 290 |
| 1891 | 299 | 1904 | 315 | 1917 | 262 |
| 1892 | 308 | 1905 | 306 | 1918 | 255 |

[1] General strike.

It cannot be denied that the conditions of mining in this coalfield are not so favourable for the production of a large output per person employed as obtains in certain other districts. The miners in South Wales set all their face roof supports, rip roof or floor in their roadways, and in many cases keep their stall roads in repair by ripping and setting roof supports. They thus spend much time away from the face and coal-getting.

In addition there are a large number of persons employed below ground who do not produce any coal. These are principally occupied in haulage, and in repairing and enlarging the main haulage roadways, return airways, and subsidiary headings, consequent on the heavy crush due to depth of cover, shale strata, and the proximity of coal-seams to each other.

In a few cases there are more men employed in other work

than that of actually producing coal, therefore under these circumstances the output per person is below that of any other district. **The President.**

The increased depths of shafts, and the distances from which coal has now to be conveyed by mechanical haulage to the bottom of the pits, must of necessity reduce the output per man employed at the face. In addition, the time taken in walking from the shaft bottom to the faces is increasing yearly, and at a few mines this distance is at present over two miles. It may be considered expedient in such cases to convey the men in and out along the planes if the condition of the planes permit.

The roof and sides of the main haulage roadways of many mines are now partially supported by arched steel girders set at regular intervals and having the webs of the girders held together by dry stone walling or brickwork at short heights above the level of the floor. This system appears to me to make excellent haulage planes, reducing liability to falls due to derailed trams displacing timber supports, and especially reducing exposed superficial areas of timber favourable to the deposition of coal-dust.

The use of steel or ferro-concrete props at the faces, although adopted to some extent in other districts, does not appear to have found favour in this coalfield.

I wish in conclusion to draw attention to a question of great importance to the engineers of this coalfield, viz. coal-dust.

There are several mines where coal-dust is very well treated on mechanical haulage planes, but little is done on other roadways. Other mines have not dealt with the subject in the manner which its importance requires. Mechanical stone crushers are now available in greater numbers than during the war period, and therefore every effort should be made to procure these in order to obtain a sufficient quantity of stone-

The President. dust for mixing with the coal-dust on the floor, roof, and sides of mines. The mixture should be periodically tested to ensure that the amount of the percentage of stone and coal-dust is in accordance with the conclusions of the Explosions in Mines Committee. Various means are adopted for the distribution of stone-dust, but the most effective from my own observation seems to be, throwing it by hand over the floor, roof, and sides. The excellent paper written on this subject by Mr. Budge, now of Llanbradach, should serve as a most useful guide to members how to obtain the desired object.

Whatever may be said as to the conduct of mining operations, our mining engineers are second to none in the kingdom, and need not be ashamed of their profession. The most modern collieries in South Wales to-day are examples of design, lay out, and equipment with the latest improvements in mechanical and electrical appliances which cannot be surpassed in any part of the world. (Applause.)

## Vote of Thanks to the President.

Dr. H. K. Jordan. Doctor H. K. Jordan said he had been asked, as the senior vice-president, to propose a vote of thanks to the President for his address. He was sure they had all appreciated the address, which was exceedingly interesting and appropriate to the occasion. He had known the President from Mr. Dyer Lewis's boyhood, and had always entertained a warm regard for him. He had every confidence that under his guidance the Institute would continue to make progress. He had heard with pleasure the suggestion that day for the revival of social functions by the Institute, which had been necessarily suspended during the war. It did them all good to mix with one another, to shake hands, and become better acquainted with each other. They would all join with him in wishing the

President a highly successful year of office, and would do all in their power, by regular attendance at the meetings and the readings and discussion of papers, to co-operate with him in achieving that success. (Applause.) **Dr. H. K Jordan.**

Mr. HUGH BRAMWELL said he had pleasure in associating himself with the resolution of thanks to the President for his address, which, appropriately, had dealt with the effects of the Great War on the coal-mining industry of South Wales, so placing them on record in the Proceedings of the Institute. With great cordiality he seconded the vote of thanks. **Mr. Hugh Bramwell.**

The motion was carried amid applause.

In response, the PRESIDENT made an appeal for papers, preferably on mining and engineering subjects, seeing that for a year or two they had had mostly papers on the mechanical side. It was not necessary, he said, to write long papers; what they wanted was a concise treatment of a problem in which they had interested themselves and probably experimented upon, stating facts based upon experience in the exercise of their vocations that would evoke the views of fellow-members. All that was needed was to put down facts on paper, as briefly as would do justice to the matter in hand, and leave them to be elaborated in discussion. They had many members, especially of the younger generation, who were engaged in development work of one kind or another; and he asked them to put themselves to a little trouble in giving the Institute the benefit of their modern knowledge. The authors themselves would probably derive additional knowledge from the experience of other members related in the discussion of the subjects treated. (Hear, hear.) **The President.**

## The Single-Field Cascade Machine.

By L. J. Hunt, M.Inst.C.E., M.I.E.E.

(Paper, *see* Proceedings, Vol. XXXV., No. 2, p. 309.)

**The President.** The President said it was rather a drawback that members had not had the printed paper in their hands for a longer time, so that they might fully grasp the technicalities of what was apparently an important machine, but he still hoped they would have an instructive discussion either at the present gathering or at the next meeting.

**Mr. W. A. Chamen.** Mr. W. A. Chamen said while he and other members of the electrical profession very greatly admired the ingenuity of Mr. Hunt's machine, yet they had experienced a little difficulty in following his complicated designs, and were therefore not in a position at the present stage to get up and criticise them. Personally, he had had no experience of using any of Mr. Hunt's motors, but hoped to have the opportunity of doing so before long. Although at first he was inclined to doubt the possibility of Mr. Hunt's ability to do what he claimed, he had come to realise that his dubiety was due to his failure to fully understand the way in which the author had achieved these remarkable results.

He was aware that some of these motors were at work in this district, and was sorry he could not see present at the meeting any members who had experience of them ; but, so far as he could learn, there was nothing in actual practice to show that they did not do what was claimed for them by Mr. Hunt. True, he had heard of a little trouble, but believed it was due to defects in manufacture which had been remedied. The motor might be described as one in which there were many windings in the slots, whereas in the ordinary motor there was only one winding. This meant, perhaps, there was a great length of very small wire. All these were coupled up in parallel,

or in some other way, which would probably baffle description by anybody but Mr. Hunt. (Laughter.) What they would have liked was a quiet talk over the table with Mr. Hunt, in order to get enlightenment on many points. Until they knew more, they must refrain from criticism or eulogy. Mr. W. A. Chamen.

Mr. Hugh Bramwell.

Mr. HUGH BRAMWELL said he believed one of the first cascade motors installed in this district was put in to drive a small air compressor at a colliery with which he had to do, and while there was some little trouble in the first instance—he forgot what it was exactly, but Mr. Davison would be able to tell them—yet it had been running for some years and gave every satisfaction.

Mr. J. W. Davison.

Mr. J. W. DAVISON said the cascade motor referred to by Mr. Bramwell had been running seven or eight years, and as far as he knew they had experienced no difficulty with it except at the commencement, when some little alterations were made, and some of the windings were strengthened. The motor had proved well adapted to the work it was intended for—to drive an air compressor. At first there was not sufficient work at the compressor for a full load on the motor, which was run for a considerable time at a slow speed, but afterwards it was put to a higher speed, and had given no trouble. He should say that for air compressors not required to be put to full load at the start, and for fans not called upon for full capacity, a cascade motor was a very suitable plant.

The President.

The PRESIDENT asked Mr. Jacob if he had experience of the cascade motor.

Mr. F. Ll. Jacob.

Mr. F. LLEWELLIN JACOB said some years ago a cascade motor was installed at a certain pit with the idea of running it at a slower speed at week-ends than during working time, and he believed it gave satisfactory results so far as their experience of it went. But there was a heavy fall in the shaft, which

Mr. F. Ll. Jacob.

reversed the windings and smashed up the cascade motor. They could not blame the motor for that. (Laughter.)

Mr. L. J. Hunt.

Mr. L. J. Hunt (the author) said in reply that Mr. Chamen had spoken of the number of windings. He would like to explain that the windings on this machine were exactly similar to the winding on an ordinary induction cylinder, except that in the stator they were parallel connected, so that for a given voltage there were twice as many wires. In the rotor there were just two bars to the slot, so that the winding was comparable to the ordinary single-winding motor. Of course, where the voltage was high, up to, say, 6,000 volts, there were a large number of small wires, but this was quite the exception. Mr. Chamen now referred to the question of 25 cycles for these machines. That meant the speed which could be attained was, of course, low, and in certain conditions this might be a disadvantage; but for haulage work, where these machines had proved useful, it meant they had a motor which could be run at 25 cycles and have no slip rings—an important point in underground working. The chief difficulty in understanding this machine would be removed if they did not look upon it as one complete machine. As a matter of fact, it was built up of two components. It was quite easy to follow if they thought of an ordinary cascade combination of two motors, where the rotor of the first machine was connected to the rotor of the second machine. Then the speed starting torque could be controlled by connected resistances to the stator of the second machine. In developing this single-field machine they had taken the idea of two separate motors, and found that by adjusting the number of poles they could combine the two motors into one; and in working out calculations in connection with these machines they simply used the same theory as if they were considering an entirely separate machine. There was really nothing complicated in the motor.

Mr. Bramwell had referred to a motor driving a 400 horse-power air compressor at the Great Western Colliery. He (Mr. Hunt) remembered something of the initial trouble there with the stator winding, but that was the first single-field cascade motor ever built, so that some excuse s ould be made for it. He did not think any other points had been raised. The paper dealt with developments that were more or less special—the new type of generator in the early stage of development, &c. It was an interesting machine, because it had been found it could be connected to the line and paralleled with other machines without the necessity of any paralleling gear, and it could be thrown on to the line when it was out of phase. Of course, all the work up to now had been on small machines, and one wanted, therefore, to see what would happen with a large machine, where they had more inertia to reckon with; but from what one could see it appeared to be a machine which might be especially suitable in connection with the gas-engine, and where it was not affected by considerable momentary variations in speed. Then, it had been found they could not produce any 'hunting' effect. This had been explained in the paper. **Mr. L. J. Hunt.**

Mr. Chamen said he had intended to ask Mr. Hunt whether any development of his invention would be capable of giving them a satisfactory phase changer, from 25 to 50 periods. This was a problem which had to be dealt with in this district, and they were looking about for better means of doing it than with two separate machines. **Mr. Chamen.**

Mr. Hunt said he was afraid he could not answer that question. It was a question that had been asked by many power engineers. It was an interesting point which had not been investigated, but it was within the bounds of possibility. **Mr. Hunt.**

The President said, as members had not had sufficient time to digest the paper, which was an important one, he would **The President.**

The President. adjourn the discussion to the next meeting. In the event of the author not being able to be present at that meeting, he would probably reply in writing to the new points raised, for its insertion in the Proceedings.

Mr. Hunt. Mr. HUNT said he would endeavour to be present to reply in person. (Hear, hear.)

The discussion was adjourned, and the proceedings closed.

## Suggested Subjects of Papers.

At the annual dinner subsequently held at the Park Hotel, the President (Mr. Dyer Lewis) threw out the following suggestions for papers to be submitted to the Institute :—

A design of colliery trams to meet the requirements of the Coal Mines Regulation Act, 1911 ;

Coal-dust, which, he said, required more attention than it had yet received ;

Re-arrangement of haulage planes ;

A departure from the rectangular and square form of heading, which was the worst way of dealing with pressure and squeeze ;

Ferro-concrete and steel arches and other forms of protecting the main haulage ;

Improvement of mechanical methods of bringing coal from long distances in view of the necessity for increased output in the seven-hour shift.

# PROCEEDINGS.

## Special Joint Meeting of the South Wales Institute of Engineers and the Society of Chemical Industry (Bristol and South Wales Section).

A SPECIAL joint evening meeting of the South Wales Institute of Engineers and the Society of Chemical Industry (Bristol and South Wales Section) was held at the University College, Cardiff, on Wednesday, March 3, 1920.

Mr. W. R. BIRD, vice-chairman of the Bristol and South Wales Section of the Society of Chemical Industry, occupied the chair, being supported by Mr. J. DYER LEWIS, H.M. Divisional Inspector of Mines, President of the South Wales Institute of Engineers; Mr. MARTIN PRICE, secretary of the South Wales Institute of Engineers; and Mr. H. E. COX, hon. secretary of the South Wales Committee of the Society of Chemical Industry. **Mr. W. R. Bird.**

## Researches on Coal.

BY MR. S. ROY ILLINGWORTH, B.SC., A.R.C.S., F.I.C.

The CHAIRMAN said they were met to hear a paper read by Mr. Illingworth on the coking of coals. Many of those present doubtless attended a meeting in the autumn, when the **The Chairman.**

The Chairman. South Wales Institute of Engineers were good enough to ask the Bristol and South Wales Section of the Society of Chemical Industry, as a young body, to join them at a general meeting of the Institute to hear Mr. Roy Illingworth read an introductory paper on the coking of coals, a subject which he had been investigating for some time. Mr. Illingworth now proposed to enter into particulars of his research.

# RESEARCHES ON COAL.

By S. Roy Illingworth, B.Sc. (Hons.), Lond., F.I.C., A.R.C.S.

PART I.—The Thermal Decomposition of Coal at Low Temperatures.
PART II.—An Investigation of certain Coking Coals.

# RESEARCHES ON COAL.

By S. Roy Illingworth, B.Sc. (Hons.), Lond., F.I.C., A.R.C.S.

## PART I.—The Thermal Decomposition of Coal at Low Temperatures.

The thermal decomposition of coal at low temperatures has been investigated from different standpoints by a number of independent workers. The lines of investigation have followed one or other of two directions:

(*a*) the examination of the gaseous products evolved at definite temperatures;

(*b*) the investigation of the nature of the liquid products evolved.

The most important results that have been published in this connection are those contained in the communications of Burgess and Wheeler (*Trans. Chem. Soc.*, 1910–1914), Porter and Ovitz (*Bulletin I.*, U.S.A. Bureau of Mines), Porter and Taylor (U.S.A. Bureau of Mines), Jones and Wheeler (*Trans. Chem. Soc.*, 1915), and other workers. A study of certain Scotch coking coals was carried out by Anderson in 1895 (*Jour. Soc. Chem. Ind.*, 1896). An excellent and critical survey of the various investigations into the decomposition of coal at moderately low temperatures is contained on pages 7–12 of the monograph on the Constitution of Coal by Doctors Stopes and Wheeler published by H.M. Stationery Office.

The present communication deals with the results of an investigation planned to elucidate the relative stability of certain known components of coal when subjected to carbonisation under standard conditions. The point of view which led to the instigation of this research was the one that in all

its commercial usages, as a fuel, in coking, gas producer or gas works practice, the coal must pass under the influence of all those variations in temperature comprised between normal atmospheric temperature and the maximum temperature attained in a particular operation. The behaviour of a coal under the influence of comparatively low temperature must play a very important, if not a fundamental, part in determining the properties of that coal.

The work here recorded embodies the relative behaviour of certain coals carbonised at various temperatures up to 450° C. The coals chosen for the purpose of the investigation are coals which when carbonised at 950° C. yield cokes of different types. The samples experimented upon were mine samples cut from roof to floor of the seam, and they comprised all told about 80–100 lb. of coal, from which a 14 lb. laboratory sample was obtained by the usual process of quartering down the bulk; this smaller sample furnished the coal actually worked upon in the investigation.

The analyses of the coals were as under:

Table I.

| | No. 2 Llantwit. | No. 3 Rhondda, S. Crop. | No. 2 Rhondda. | Two Foot Nine, S. Crop. |
|---|---|---|---|---|
| Volatile . . . | 37·06 | 31·50 | 21·16 | 26·24 |
| Fixed Carbon . . | 57·53 | 66·93 | 71·20 | 71·26 |
| Ash . . . | 5·41 | 1·57 | 7·74 | 2·50 |
| On dry ash-free Coal: | | | | |
| C. . . . . | 82·87 | 86·70 | 87·96 | 87·70 |
| H. . . . . | 5·80 | 5·00 | 4·35 | 4·94 |
| O. . . . . | 7·76 | 6·21 | 4·32 | 5·39 |
| N. . . . . | 1·49 | 1·45 | 1·42 | 1·34 |
| S. . . . . | 2·08 | 0·64 | 1·95 | 0·63 |
| Ratio $\frac{C}{H}$ . . . | 14·29 | 17·54 | 20·22 | 17·75 |

The No. 2 Llantwit is used for the purpose of gas making, and yields a very porous coke. On the basis of the classification of coals revised by Professor Bone and set out on page 64 of his book 'Coal and Its Uses,' the No. 2 Llantwit must be classed as a 'coking long flame coal of the bituminous genus.'

The No. 3 Rhondda is carbonised for the production of metallurgical coke, and is also utilised in the gas industry. The coal yields a dense coke which tends to be of a brittle nature. The above analysis places this coal in the class of *Hard Coking Bituminous Coals*, and it may be regarded as possessed of a nature intermediate between that of the gas coals and the typical coking coals. The Two Foot Nine is a typical hard coking coal, whilst the No. 2 Rhondda is a 'hard coking (short flame) coal,' and gives rise to a dense coke.

The method of investigation followed in the research was in brief to submit a known weight of the coal, ground to the same degree of fineness, to the influence of definite fixed temperatures for varying intervals of time, and determine the loss of weight produced. In so much as the liquid products produced were not completely volatile at the temperatures maintained in the work, the residue from each heating operation was washed with cold carbon tetrachloride in order to remove the oily substances, dried in vacuo at 105° C., and then weighed. The loss of weight was based on the washed and dried residue. A known weight of the final residue was extracted with pyridine in a soxhlet apparatus, and the pyridine extract after it had been dried was extracted with chloroform. This cycle of operations furnished the data necessary to calculate the amount of the pyridine soluble compounds, the gamma or resinic bodies, and the beta cellulosic substances in the residues remaining from 100 parts of the coal substance

at the end of the various periods of time, during which the coal had been subjected to the influence of a particular temperature. The terms beta and gamma compound are used in conformity with the terminology proposed by Wheeler. The beta compound is that portion of the coal soluble in pyridine but insoluble in chloroform, whilst the gamma compound is that portion of the coal soluble in both pyridine and chloroform. The methods of conducting the individual processes in the cycle of operations outlined above were as follows:

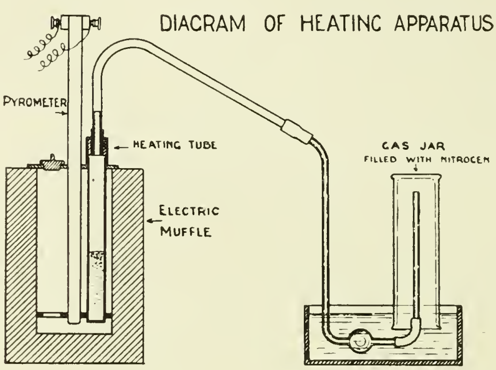



Fig. 1.

*Drying.*--All coals, extracts, or residues were dried in a vacuum oven maintained at a temperature of 105° C., the pressure in the oven being 6 cm. of mercury.

*Heating the Coals.*—The sample of coal used for this operation was of such a degree of fineness that it would all pass through a 30-mesh sieve and be retained on a sieve of 60 mesh. The weight of dry coal used was 25 grammes for each charge. The apparatus used for the heating operation is shown in Fig. 1. This apparatus comprised an electric muffle 2 in. × 4 in. × 10 in., the front end of which was closed by a steel plate provided with two lateral holes for the heating tubes, and a central hole to take a pyrometer. A guide plate

within the oven was held in position by two tie-rods connected with the front plate, and it served the purpose of ensuring that the tubes did not come in contact with the walls of the oven. The muffle was placed on its back, so that during the heating operation the tubes were in a vertical position. The tubes in which the coals were heated were made from 1-inch Mannesman tube, closed at one end by a straight-face plug welded in; the other end of the tube was bushed to receive a plug, through which passed a $\frac{3}{8}$-inch tube bent at an angle of 75° to the vertical. The tubes were turned down to $\frac{1}{16}$-inch walls, and a shoulder was left so that just 10 inches of the tube were inserted in the oven when this shoulder was flush with the front plate. The tubes were similar in all respects. The weighed charge of dry coal was placed in the tubes, the upper threads of the plug were coated with a thin fillet of glycerine and litharge cement, and then screwed tightly into position in the tube. Each tube was exhausted, filled with dry nitrogen, and the open end of the delivery tube closed up airtight by a rubber cap. The front end of the furnace was closed by covers over the orifices for the heating tubes, and brought to the required temperature of the experiment. A steady condition of temperature of the muffle was regarded as having been attained if no fluctuation in temperature greater than 5° C. was recorded in an hour. The charge tube was then inserted into the oven, due care being taken that the shoulder on the tube was flush with the front plate. Immediately on insertion of the tube the delivery tube was connected to a vessel containing nitrogen. This vessel consisted of an ordinary gas jar inverted in water; reaching to the top of the jar was a glass tube connecting through the bulb and glass tube with the exit of the heating tube. The time requisite for the whole charge to reach the temperature of the oven was determined by performing blank experiments with the thermo-couple

placed in the centre of the charge, and the time that elapsed between the insertion of the tube and the recording by means of the thermo-couple of the same temperature as that shown by the pyrometer in the oven was noted. It was found that when the oven was stabilised at 450° C. half an hour was required for the charge to attain this temperature. When the oven temperature was 400° C., a period of 40 minutes elapsed before the coal was uniformly heated, whilst 45 minutes was necessary for the establishment of equilibrium at 350° C. The tubes were heated one by one, and throughout the period the variation of the temperature of the oven did not exceed 5° C. At the expiration of the particular period of heating the exit tube of the charged tube was attached to a nitrogen supply, the heating tube was withdrawn from the furnace, and cooled by gradually lowering it into water. The residue was carefully removed by special tools and brushes from the cooled tube and rapidly weighed, then placed in a flask and covered with carbon tetrachloride. The flask was shaken for three or four minutes, allowed to stand for one hour, and the mixture then filtered at the pump. The residue was washed with carbon tetrachloride, dried in vacuo for two hours, and finally weighed. Repeat determinations of the loss of weight of a coal at a particular temperature during a specified interval of time agreed within the limit $\pm$ 0·2 per cent.

*Pyridine Extractions.*—The coal or residue to be extracted was ground up, and over 5 grammes of that portion which passed an 80-mesh sieve but was retained on a 90-mesh sieve was weighed out and dried in vacuo for one hour. An exact 5 grammes was then weighed out, mixed with an equal weight of ignited sodium chloride, and the mixture placed in a dry double-walled extraction thimble, the mouth of which was closed with a plug of dry cotton-wool. The soxhlet apparatus

used was of the 100 c.c. type, made wholly of glass. The end of the condenser was connected to a three-way limb, one portion of which was used for filling the apparatus with nitrogen by first evacuating the apparatus and subsequently connecting up to a supply of dry nitrogen. This limb was closed during the period of extraction. The other member of the three-way limb was connected to the manometer tube which served the double purpose of controlling the evacuation of the air and subsequently allowing for variation of pressure within the apparatus. The flask of the apparatus was heated on a sand bath and surrounded by a metal cylinder lined with asbestos. The burner was so regulated that the syphon functioned every 12 minutes. The pyridine used was prepared from the commercial product by fractional distillation, and it distilled entirely between the limits 116° C. and 122° C. The pyridine used for the extractions was dried by repeated agitation with solid caustic potash, with which it was always in contact in store. The extraction was conducted with 250 c.c. of pyridine as follows:

The apparatus was kept continuously at work for 120 hours, then allowed to cool, and a fresh charge of pyridine placed in the flask. The charge in the thimble was well stirred and the apparatus recharged with nitrogen, after which the extraction was continued for a further 72 hours. The charge in the thimble was again well mixed and, after refilling with nitrogen, the apparatus was kept at work for a final period of 48 hours. The first pyridine extract was kept till the close of the operation in a glass-stoppered flask filled with nitrogen, and the stopper and neck were covered with a rubber cap. The pyridine extracts were mixed together, concentrated down to a convenient bulk by distilling off a portion of the pyridine in an atmosphere of carbon dioxide, and the cold residue was slowly poured into an excess of hydrochloric

acid of 1–1 strength made with air-free water. The precipitate was filtered on to a tared filter-paper held in a Buchner funnel, washed until it was acid free, dried for eight hours in vacuo, and then weighed.

A definite weight of the dried extract was extracted with pure dry chloroform in an apparatus similar to that used for the pyridine extractions, only in this case the flask was heated in a water bath; the extractions were continued for at least one day from the time the chloroform in the extraction chamber had become colourless, a stage which was generally reached about forty-eight hours from the commencement of the process. The chloroform solution was filtered through a tared paper, and the weight of any beta cellulose mechanically carried over was added to that determined by weighing the contents of the thimble after it had been dried in vacuo for two hours. The amount of beta cellulose present in any coal or residue is based on the direct weight obtained by the above method. In every case the resinic matter was determined by distilling off the chloroform in a tared flask and subsequently weighing the residue of resins, but the results for resin are taken by difference between the amounts of pyridine soluble and the beta cellulose. The investigation necessitated the preparation of comparatively large amounts of the beta cellulose and resinic substances. These were prepared by extracting in an atmosphere of nitrogen a definite amount of coal contained in a metal flask, which was heated on an air bath, and the pyridine extract was subsequently extracted with chloroform in a soxhlet apparatus.

*Volatile.*—The figures for volatile matter were determined by heating one gramme of coal, etc., in a platinum crucible for seven minutes in an electric muffle maintained at the temperature specified, the temperatures being recorded by a thermo-couple placed alongside the crucible.

*Sulphur.*—This constituent of the coals' residues or extracts was determined by the Eccka method.

*Nitrogen.*—The nitrogen content of the various substances was determined by the modified Gronig Kjeldahl method. The ammonia from this treatment was distilled into 10 c.c. of standard acid, the excess of which was determined by titration with N/10 ammonia solution, using cochineal as the indicator.

*Method of Calculation.*—All results unless otherwise specified are calculated to an ash free and dry basis. Such figures are subsequently referred to as based on the coal substance. The amount of any constituent present in the residue derived from 100 grammes of coal substance was calculated by the following formula:

$$\text{Amount} = \frac{x \times y \times 100}{z}$$

where $x$ = percentage of the constituent present in the residue;

$y$ = weight of residue from one gramme of the original dry coal;

$z$ = 100—percentage of ash in the original dry coal.

*Pyridine Extraction of the Original Coal.*—In the course of the study of the behaviour of the coals at a temperature of 450° C. various anomalous results were obtained for the amount of substance extracted by pyridine from the residues arising after comparatively short intervals of heating. In nearly every case an enhanced amount of the coal substance was soluble in pyridine, a result in agreement with the observations of Harger (*Jour. Soc. Chem. Ind.*, vol. 33 (1914), pp. 389, 393). Since it was found necessary to maintain the charge of coal for a period of half an hour at a temperature of 450° C. before the charge was in thermal equilibrium with its surroundings, the rate of the decomposition of the coal substance was based upon the residue resulting from placing the heating tube

for half an hour in the muffle regulated to maintain a constant temperature of 450° C. During this half-hour interval the temperature of the muffle fell to 370° C. and then gradually rose to 450° C., which temperature was reached in twenty-five minutes from the insertion of the tube. The amounts of the various substances present in these residues thus obtained are given in Table II.

Table II.—Constituents present in Residue from ½-hour Treatment of the Coals at 370–450° C. Percentage Constituents in Residue from Ash-free Dry Coal.

| Coal. | Pyridine Soluble. | α Cellulosic. | β Cellulosic. | Resinic. |
|---|---|---|---|---|
| No. 2 Llantwit . | 31·97 | 68·03 | 24·26 | 7·71 |
| No. 3 Rhondda, S. Crop . . . | 30·98 | 69·02 | 19·77 | 11·21 |
| No. 2 Rhondda . | 28·41 | 71·59 | 17·56 | 10·85 |
| Two Foot Nine, S. Crop | 31·99 | 68·01 | 20·07 | 11·92 |

The percentage amounts of the various constituents determined by direct extraction of the virgin coal are given in Table III., from which it is evident that the enhanced values of the pyridine soluble figure is greater in the case of the true coking coals.

Table III.—Percentage of Constituents in the Coal Substance determined by Direct Extraction of the Coal.

| Coal | Pyridine Soluble. | α Cellulosic. | β Cellulosic. | Resinic. |
|---|---|---|---|---|
| No. 2 Llantwit . | 28·06 | 71·94 | 18·41 | 9·65 |
| No. 3 Rhondda, S. Crop . . . | 33·37 | 66·63 | 19·30 | 14·07 |
| No. 2 Rhondda . | 7·62 | 92·38 | 2·69 | 4·93 |
| Two Foot Nine, S. Crop | 21·08 | 78·92 | 16·74 | 4·34 |

The reasons for the different properties of these coals are to be sought rather in the nature of their various constituents than in the quantity present. Further work on the nature of the various constituents is proceeding. Meanwhile the following characteristics reveal marked differences in the several constituents from the different coals:

Table IV.—Analysis of $\beta$ Cellulosic Constituents.

| | No. 2 Llantwit. | No. 3 Rhondda. | No. 2 Rhondda. | Two Foot Nine. |
|---|---|---|---|---|
| C. | 77·56 | 80·50 | 83·77 | 83·08 |
| H. | 4·34 | 4·00 | 4·95 | 4·72 |
| O. | 14·91 | 12·92 | 8·58 | |
| N. | 1·00 | 2·01 | 1·87 | 12·20 |
| S. | 2·19 | 0·57 | 0·83 | |
| Ratio $\frac{C}{H}$ | 17·86 | 20·12 | 16·92 | 17·60 |
| Volatile 950° C. | 37·50 | 27·01 | 28·69 | — |

Table V.—Analysis of Resinic Constituents.

| | No. 2 Llantwit. | No. 3 Rhondda. | No. 2 Rhondda. | Two Foot Nine. |
|---|---|---|---|---|
| C. | 83·37 | 85·24 | 86·16 | 85·76 |
| H | 7·71 | 6·97 | 6·31 | 6·53 |
| O. | 4·99 | 9·10 | | |
| N. | 1·24 | 1·37 | 1·00 | 7·71 |
| S. | 2·69 | 0·32 | (N,S) 6·53 | |
| Ratio $\frac{C}{H}$ | 10·81 | 11·94 | 13·66 | 13·12 |
| Volatile 950° C. | 80·98 | 69·45 | 64·21 | — |

The above ultimate analyses reveal the same gradation in nature of the constituents as exists amongst the coals, and again indicate that the No. 3 Rhondda is intermediate in nature between the gas-making coals and the true coking

coals; but no generalisation as to the various factors determining the coking qualities are evident from a survey of these figures.

The endeavour to elucidate (by investigation of the thermal stability of the several components) the causes of the variation of the nature of the coke produced by these coals was then undertaken. Considerable differences in the stability of the coals were shown by the behaviour under the influence of temperatures of 350° C., 400° C., and 450° C. for varying

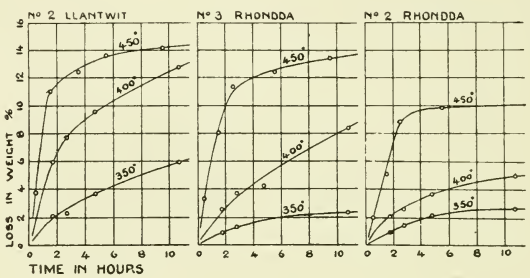



Fig. 2.

intervals of time. The results for the percentage loss of weight of coal substance at the particular temperature during the intervals of time specified are given in Tables VI., VII., and VIII., and the results are represented graphically in Fig. 2.

The periods are timed from insertion of the tube into the oven stabilised at 350° C. In every case the whole of the residue was readily emptied out of the tube, it exhibited no sign of cohesion, and the edges of the individual particles were as sharp as those of the original charge. These facts preclude the idea that the residue had melted or softened. Anderson, it will be recollected, gave 300° C. as the softening point of the Scotch coking coals he examined, whereas the above coals do not soften or coke at 350° C. The above figures show that

the No. 2 Llantwit is the least stable of the coals examined and that the other two coals are of the same order of stability at this temperature.

Table VI.—Percentage Loss of Weight of Coal Substance at 350° C.

| Coal. | Hours of Heating. | | | |
|---|---|---|---|---|
| | $1\frac{3}{4}$. | $2\frac{3}{4}$. | $4\frac{3}{4}$. | $10\frac{3}{4}$. |
| No. 2 Llantwit . | 2·14 | 2·24 | 3·66 | 5·94 |
| No. 3 Rhondda . | 0·85 | 1·25 | — | 2·27 |
| No. 2 Rhondda . | 0·91 | 1·34 | 2·00 | 2·43 |

Table VII.—Percentage Loss of Weight of Coal Substance at 400° C.

| Coal. | Hours of Heating. | | | | Remarks. |
|---|---|---|---|---|---|
| | $1\frac{3}{4}$. | $2\frac{3}{4}$. | $4\frac{3}{4}$. | $10\frac{3}{4}$. | |
| No. 2 Llantwit | 5·93 | 7·73 | 9·52 | 12·77 | Residues had all coked. |
| No. 3 Rhondda | 2·6 | 3·73 | 4·26 | 8·43 | Do. |
| No. 2 Rhondda | 2·15 | 2·54 | 3·61 | 4·77 | No residue had coked. |

The curves in Fig. 2 show that the No. 2 Llantwit is undergoing progressive decomposition at this temperature to a very considerable extent. The No. 3 Rhondda is decomposing in a progressive manner at a slower rate whilst by comparison the No. 2 Rhondda is only decomposing at a very slow rate. These curves may represent the decomposition of certain constituents unstable at 400° C. which are present in considerable amount in the No. 2 Llantwit, present to a lesser degree in the No. 3 Rhondda, and represent a much smaller

portion of the No. 2 Rhondda. The cokes resulting from the first two coals were very brittle and possessed a very bright appearance—one might term them 'Coal Bright'; the individual particles comprising the cokes had very rounded edges. The whole of the various charges of the No. 2 Rhondda were easily poured from the tubes, and the particles of the residue were possessed of sharp unaltered edges—a fact which leads one to believe that no softening of the coal had taken place at this temperature.

TABLE VIII.—PERCENTAGE LOSS OF WEIGHT OF COAL SUBSTANCE AT 450° C.

| Coal. | Period of Heating (Hours). | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | ½. | 1½. | 2½. | 3½. | 5½. | 9½. | 12½. | 24½. |
| No. 2 Llantwit | 3·85 | 11·09 | — | 12·47 | 13·68 | 14·17 | — | 15·14 |
| No. 3 Rhondda | 3·36 | 8·13 | 8·82 | 11·42 | 12·43 | 13·53 | — | 15·81 |
| No. 2 Rhondda | 1·86 | 5·07 | 8·87 | — | 9·84 | — | 10·06 | 10·16 |
| Two Foot Nine | 2·38 | 8·28 | — | 11·07 | 11·76 | — | 11·98 | 12·01 |

These figures and the curves in Fig. 2 reveal the rapid initial decomposition of the coals at this temperature and the greater volatility of the first two coals compared to the volatility of the coking coals. It is interesting to note that the dense coking coals approach their maximum volatile figure at this temperature in a comparatively short interval of time, whilst the other two coals approach the volatile figure under these conditions in a more gradual manner. The residues were coked in every case, with the exception of that residue resulting from the half-hour treatment of the No. 2 Rhondda. This residue had cohered into lumps in various places, and the whole mass exhibited definite signs that incipient softening of the coal had taken place.

It is evident from the above results that the lowest temperature at which any of these coals commences to coke varies with the nature of the coal; but from the results here considered, 400° C. may be taken as the minimum temperature of coke formation for the porous coking coals, and that in all probability the dense coking coals do not coke until they attain a temperature between 430° and 450° C. In view of these results the thermal behaviour of the $\beta$ cellulosic and resinic constituents in the coals was investigated at a temperature of 450° C. This is the lowest temperature suitable for a comparison of the substances in the various coals.

## Relative Stability of Beta Cellulosic and Resinic Constituents.

### *No. 2 Rhondda.*

Table IX.—Percentage Amount of Constituents present in Residues arising from Coal at 450° C.

| Period (Hours). | Per Cent. in Residue. | | | Present in Residue *ex* 100 Coal Substance. | | |
|---|---|---|---|---|---|---|
| | Pyridine Soluble. | $\beta$ Cellulosic. | Resinic. | Pyridine Soluble. | $\beta$ Cellulosic. | Resinic. |
| ½ . | 26·66 | 16·48 | 10·18 | 28·41 | 17·56 | 10·85 |
| 1½ . | 21·33 | 31·34 | 7·99 | 22·04 | 13·79 | 8·25 |
| 2½ . | 9·23 | 4·22 | 5·01 | 9·18 | 4·19 | 4·99 |
| 5½ . | 4·10 | 0·98 | 3·12 | 4·04 | 0·96 | 3·08 |
| 12½ . | 3·2 | 0·6 | 2·6 | 3·14 | 0·58 | 2·56 |
| 24½ . | 1·9 | nil | 1·90 | 2·10 | nil | 2·10 |

The results for the weight of the various components present in the residues from 100 gms. of coal substance are represented in Fig. 3.

The rapid destruction of the pyridine soluble constituents

in the first two hours of the treatment is very evident, and further the rapid decrease in the amount of substance soluble

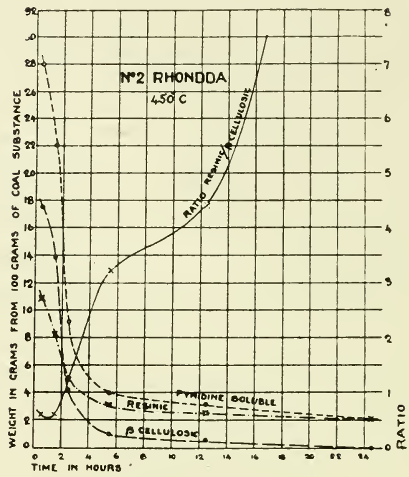



Fig. 3.

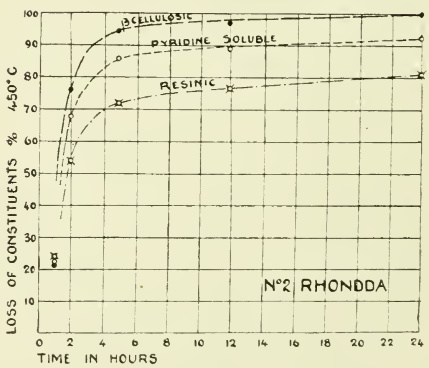



Fig. 4.

in pyridine is due in a greater degree to the destruction of the $\beta$ cellulose than to the destruction of the resinic substance. The relative ease of decomposition of the several constituents is more marked in Fig. 4, which has been arrived at as follows:

The amount of the various constituents present in the half-

hour residue is taken as the starting-point for the purpose of the calculation of the rate of decomposition of the coal substance; by subtracting from the half-hour values the amounts of any constituent present at the end of a particular period of heating the loss of that constituent in the period is found, and this loss is expressed as a percentage of the amount present in the half-hour residue. The results are detailed in Table X.

Table X.—Percentage Loss of Constituents at End of Periods based on Half-hour Period as Starting-point.

| Period from ½ hour. | Weight lost on 100 Parts Ash-free Substance. | | |
|---|---|---|---|
| | Pyridine Soluble. | β Cellulosic. | Resinic. |
| 1 hour . . . . | 22·42 | 21·52 | 23·97 |
| 2 hours . . . . | 67·76 | 76·33 | 54·01 |
| 5 ,, . . . . | 85·70 | 94·75 | 71·61 |
| 12 ,, . . . . | 88·94 | 96·94 | 76·33 |
| 24 ,, . . . . | 92·62 | 100·00 | 80·65 |

The curves in Fig. 4 emphasise the more rapid decomposition of the $\beta$ cellulosic relative to the resinic substances. The curves for both the $\beta$ cellulosic and resinic constituents tend to exhibit a point of flexure at the end of the five-hour period, a fact no doubt due to the presence of two types of compound in each of these constituents. The one type, A, readily decomposed at 450° C., the other type, B, more stable at this temperature. The fact that the point of flexure in the curve for the $\beta$ cellulosic occurs when more than 90 per cent. of this constituent has been decomposed suggests that this type of constituent in the No. 2 Rhondda approximates to a homogeneous substance. An alternative view to account for the point of flexure is the one that the slower rate of change

of these compounds in the later periods is due to the decomposition of secondary products still soluble in pyridine which arise from the destruction of the primary. Analyses of several of the $\beta$ cellulosic and resinic components isolated from various residues are given in Table XI.

Table XI.

| | $\beta$ Cellulosic | | Resinic. | |
|---|---|---|---|---|
| | ½-hour. | 2-hour. | ½-hour. | 2-hour. |
| C. . . . . . | 83·77 | 83·58 | 86·16 | 88·65 |
| H. . . . . . | 4·95 | 4·89 | 6·31 | 5·95 |
| O.N.S. by difference . | 11·28 | 11·53 | 7·53 | 5·40 |
| Ratio C/H . . | 16·92 | 17·06 | 13·66 | 14·91 |

These figures confirm the homogeneity of the $\beta$ cellulosic constituents in so much as no great difference is produced by partial destruction; the resinic substances appear to be less homogeneous than the $\beta$ cellulosic constituents; the more stable resins have a greater C/H ratio than the resins less stable at this temperature.

In so much as the $\beta$ cellulosic substances decompose more rapidly than the resinic bodies, the ratio of the resinic to $\beta$ cellulosic substance must increase as decomposition of the coal proceeds.

*Nitrogen and Sulphur.*—The nitrogen and sulphur was estimated in the various residues, and the amount present in the residues arising from one hundred parts of the coal substance was calculated from the figures thus obtained; details of the results are given in Table XII.

These results show that the decomposition at 450° C. of the nitrogenous substance present in the coal results in the

elimination of approximately 15 per cent. of the total nitrogen in the coal. The nitrogenous substance decomposed is markedly unstable at temperature in so much as such decomposition as ensues is completed in the first two hours. The subsequent figures agree within the limits of experimental error. The

TABLE XII.—NITROGEN AND SULPHUR IN RESIDUES *ex* 100 GMS. COAL SUBSTANCE, NO. 2 RHONDDA, AT 450° C.

| Period of Heating (Hours). | Percentage. | Period Loss. | Percentage. | Period Loss. |
|---|---|---|---|---|
| Original Coal . . | 1·42 | — | — | — |
| 1½ . . . | 1·38 | 0·04 | 1·99 | — |
| 2½ . . . | 1·25 | 0·13 | 1·90 | 0·09 |
| 5½ . . . | 1·21 | 0·04 | 1·79 | 0·11 |
| 12½ . . . | 1·23 | — | 1·57 | 0·22 |
| 24½ . . . | 1·25 | — | 1·61 | — |

continuous elimination of sulphur over the first period of twelve hours indicates the gradual decomposition of sulphur compounds moderately stable at 450° C.

*Two Foot Nine Seam. Temperature,* 450° C.

TABLE XIII.—PERCENTAGE AMOUNTS OF CONSTITUENTS PRESENT IN RESIDUES ARISING BY MAINTAINING THE COAL FOR VARIOUS PERIODS AT 450° C.

| Period (Hours). | Per Cent. in Residue. | | | Amount in Residue *ex* 100 Coal Substance. | | |
|---|---|---|---|---|---|---|
| | Pyridine Soluble. | β Cellulosic. | Resinic. | Pyridine Soluble. | β Cellulosic. | Resinic. |
| ½ . | 31·94 | 20·04 | 11·90 | 31·99 | 20·07 | 11·92 |
| 1½ . | 18·40 | 9·78 | 8·62 | 17·36 | 9·22 | 8·14 |
| 2½ . | 13·68 | 7·32 | 6·36 | 12·47 | 6·51 | 5·79 |
| 5½ . | 7·43 | 2·92 | 4·51 | 6·72 | 2·64 | 4·08 |
| 24½ . | 1·12 | nil | 1·12 | 1·01 | nil | 1·01 |

These results calculated to the basis of coal substance are represented in Fig. 5.

There is a general similarity of this set of curves to those in Fig. 3, due to the two coals behaving in a cognate manner. It is evident that definite points of flexure are not so marked

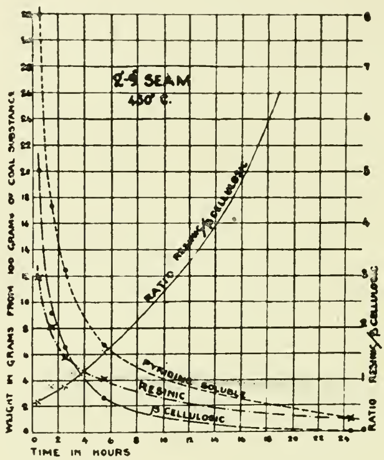



FIG. 5.

in Fig. 5 as in Fig. 3, moreover the initial decomposition of the coal substance is not so rapid in this coal as it is in the case of No. 2 Rhondda.

TABLE XIV.—PERCENTAGE LOSS OF CONSTITUENTS AT END OF PERIOD, BASED ON CONTENT OF THE ½-HOUR RESIDUE AT 450° C.

| Period (Hours). | Per Cent. Loss. | | |
|---|---|---|---|
| | Pyridine Soluble. | β Cellulosic. | Resinic. |
| 1 . . . | 45·74 | 54·08 | 31·71 |
| 2 . . . | 61·01 | 67·56 | 51·42 |
| 5 . . . | 78·68 | 86·84 | 65·77 |
| 24 . . . | 96·85 | 100·00 | 91·52 |

The percentage loss of the various constituents with lapse of time is given in Table XIV., which has been calculated in the same manner as Table X.

The results in Table XIV. are represented graphically in Fig. 6.

These curves emphasise the slower initial decomposition of the various constituents of this coal compared to the No. 2 Rhondda. The approach to homogeneity of the

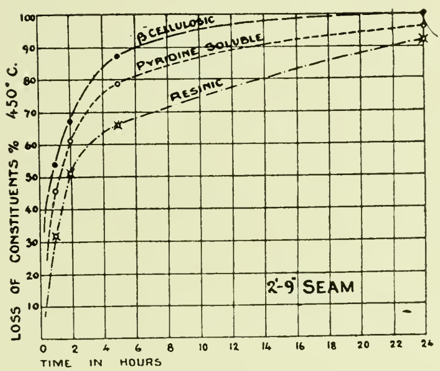



FIG. 6.

β cellulosic constituent is indicated, but the homogeneity is not quite so pronounced as in the case of the No. 2 Rhondda.

The curve denoting the variations of the ratio of the amount of resinic constituents to the amounts of β cellulosic bodies is of the same general trend as the similar curve for No. 2 Rhondda. These coals exhibit a close similarity in their behaviour and mode of decomposition at 450° C. Analyses of various constituents isolated from several of the residues are given in Table XV.

Homogeneity of the β cellulosic is not indicated by these results.

*Nitrogen and Sulphur.*—The amounts of nitrogen and sulphur in the residues, calculated on the basis of the residue

arising from 100 parts of coal substance, are detailed in Table XVI.

TABLE XV.

| | β Cellulosic. | | Resinic. | |
|---|---|---|---|---|
| | 1½-hour Residue, 450° C. | 5½-hour Residue, 450° C. | 1½-hour Residue, 450° C. | ½-hour Residue. |
| C. . . | 83·08 | 82·85 | 87·80 | 85·76 |
| H. . . | 4·72 | 4·19 | 6·43 | 6·53 |
| O.N.S. . | 12·20 | 13·96 | 5·77 | 7·71 |
| Ratio C/H . | 17·60 | 19·77 | 13·67 | 13·13 |

TABLE XVI.—NITROGEN AND SULPHUR IN RESIDUES *ex* 100 GMS. COAL SUBSTANCE, TWO FOOT NINE, AT 450° C.

| Duration of Heating (Hours). | Per Cent. Nitrogen in Residue. | Per Cent. Sulphur in Residue. |
|---|---|---|
| Original Coal . . . . | 1·34 | 0·63 |
| 1½ . . . . . . . | 1·34 | 0·63 |
| 3½ . . . . . . . | 1·26 | 0·63 |
| 5½ . . . . . . . | 1·29 | 0·69 |
| 12½ . . . . . . . | 1·31 | 0·67 |
| 24½ . . . . . . . | 1·34 | 0·69 |

It is evident that in the case of this coal the early stages of decomposition are not associated with the destruction to any appreciable extent of molecules containing nitrogen or sulphur.

*No. 3 Rhondda, S. Crop.*

The results based on the coal substance are shown in Fig. 7, from which it is evident that β cellulosic is associated with

the resinic substances throughout the period of heating, and that the decrease in the amount of these substances present

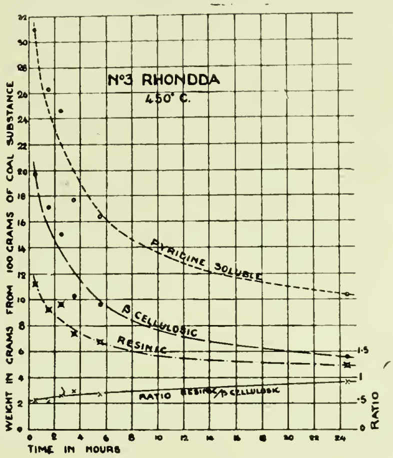



Fig. 7.

Table XVII.—Percentage Amount of Constituents in Residues obtained at 450° C.

| Duration of Heating (Hours). | Per Cent. in Residue. | | | Amount in Residue *ex* 100 Coal Substance. | | |
|---|---|---|---|---|---|---|
| | Pyridine Soluble. | β Cellulosic. | Resinic. | Pyridine Soluble. | β Cellulosic. | Resinic. |
| ½ . | 31·22 | 19·93 | 11·29 | 30·98 | 19·77 | 11·21 |
| 1½ . | 28·20 | 18·34 | 9·86 | 26·34 | 17·14 | 9·20 |
| 2½ . | 26·62 | 16·29 | 10·34 | 24·60 | 15·03 | 9·57 |
| 3½ . | 19·66 | 11·43 | 7·58 | 17·66 | 10·27 | 7·39 |
| 5½ . | 18·36 | 10·78 | 5·30 | 16·33 | 9·61 | 6·72 |
| 24½ . | 12·14 | 6·41 | 5·37 | 10·37 | 5·48 | 4·89 |

with the variation in the time of heating is far less rapid than is the case in the two coals which have so far been discussed.

The percentage losses of the constituents with variation in the duration of heating are given in Table XVIII.

TABLE XVIII.—PERCENTAGE LOSS OF CONSTITUENTS AT END OF PERIOD, BASED ON CONTENT OF THE ½-HOUR RESIDUE, AT 450° C.

| Period (Hours). | Per Cent. Loss. | | |
|---|---|---|---|
| | Pyridine Soluble. | β Cellulosic. | Resinic. |
| 1 . . . | 14·66 | 13·30 | 17·93 |
| 2 . . . | 20·60 | 23·93 | 14·64 |
| 3 . . . | 43·01 | 48·04 | 34·08 |
| 5 . . . | 46·93 | 51·30 | 40·90 |
| 24 . . . | 66·53 | 72·26 | 56·46 |

These results are represented graphically in Fig. 8.

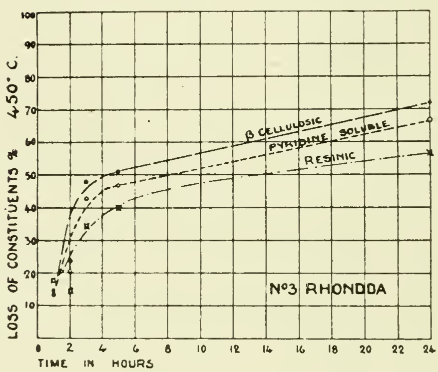



FIG. 8.

It is evident that the pyridine soluble constituents of this coal are more stable than the corresponding substances in the Two Foot Nine and No. 2 Rhondda, for in the latter coals approximately 95 per cent. of the pyridine soluble constituent is decomposed in twenty-four hours, against only 66 per cent. in the case of this coal. A point of flexure in the curves for the β cellulosic bodies occurs when 50 per cent. of this substance has been decomposed ; the curve for the resinic bodies tends to exhibit no definite change of direction. These facts can be

interpreted on the basis that the $\beta$ cellulose comprises nearly equal amounts of substances of different stability at 450° C., whilst the resinic bodies approach to a homogeneous nature. Contrasting the behaviour of these substances with the corresponding constituents of the Two Foot Nine and No. 2 Rhondda, the marked stability of the $\beta$ cellulose in this coal is very evident; moreover, the curve for the ratio of the resinic bodies to the $\beta$ cellulosic substances in the residues is emphatically different in type from the similar curves arising from the treatment of the two first-named coals. This comparatively slow rise in the value of the ratio is due not only to the greater stability of the $\beta$ cellulose but also to a corresponding greater stability of the resins in this coal as compared to the resinic constituents contained in the other coals; a fact readily evident by comparison of the resinic curves for each coal and emphasised by the fact that the extent of decomposition of the resins in the No. 3 Rhondda only reaches in 24 hours the same value as is reached in the case of the other coals in $2\frac{1}{2}$ hours. Whilst discussing this particular coal it will be of value in the sequel to note that by prolongation of the curves for the $\beta$ cellulosic and resinic bodies it becomes evident that the whole of the $\beta$ cellulose will be decomposed at the end of forty-eight hours' treatment

Table XIX.

| Residue. | $\beta$ Cellulosic. | | Resinic. | |
|---|---|---|---|---|
| | Original. | 2-hour, 450° C. | Original. | 24-hour, 450° C. |
| C. . . | 80·50 | 83·03 | 82·80 | 83·16 |
| H. . . | 4·00 | 4·76 | 6·96 | 6·16 |
| O.N.S. . | 15·50 | 12·21 | 10·24 | 10·68 |
| Ratio C/H . | 20·12 | 17·43 | 11·88 | 12·47 |

at 450° C., and that when this has taken place the resins will have undergone decomposition to an extent of 66 per cent. of the amount originally present in the coal.

Analyses of β cellulosic and resinic substances isolated from various residues are given in Table XIX.

The approach of the resins to homogeneity is evident from the above table.

*Nitrogen and Sulphur:*

TABLE XX.—THE AMOUNTS OF NITROGEN AND SULPHUR PRESENT IN THE RESIDUES FROM 100 PARTS OF COAL SUBSTANCE, AT 450° C.

| Duration of Heating (Hours). | Per Cent. Nitrogen. | Per Cent. Sulphur. |
|---|---|---|
| Original Coal Substance . | 1·45 | 0·63 |
| 1½ . . . . . | 1·20 | 0·50 |
| 3½ . . . . . | 1·28 | 0·50 |
| 5½ . . . . . | 1·27 | 0·51 |
| 9½ . . . . . | 1·28 | 0·54 |
| 24½ . . . . . | 1·22 | 0·56 |

It is evident from these results that approximately 14 per cent. of the nitrogen present is eliminated from this coal at 450° C., and in so much as this occurs within the first hour and a half of treatment the nitrogenous constituent decomposed is relatively unstable at this temperature. Associated with the decomposition of this nitrogenous substance is the elimination of 20 per cent. of the total sulphur present in the coal, no doubt due to the destruction of an organic sulphur-containing substance of the same order of stability as the above nitrogenous constituent.

*No. 2 Llantwit. Temperature,* 450° *C.*

The results calculated to the amount in the residue *ex* 100 parts coal substance are represented in Fig. 9, from which

Table XXI.—Percentage Amount of Constituents in Residues obtained at 450° C.

| Duration of Heating (Hours). | Per Cent. in Residue. | | | Amount in Residue *ex* 100 Coal Substance. | | |
|---|---|---|---|---|---|---|
| | Pyridine Soluble. | β Cellulosic. | Resinic. | Pyridine Soluble. | β Cellulosic. | Resinic. |
| ½ . | 31·38 | 23·80 | 7·56 | 31·97 | 24·26 | 7·71 |
| 1½ . | 19·04 | 11·67 | 7·37 | 18·02 | 11·04 | 6·98 |
| 5½ . | 15·67 | 10·34 | 5·33 | 14·42 | 9·50 | 4·92 |
| 9½ . | 14·38 | 8·35 | 5·63 | 13·16 | 7·63 | 5·13 |
| 24½ . | 9·49 | 4·50 | 4·99 | 8·58 | 4·07 | 4·51 |

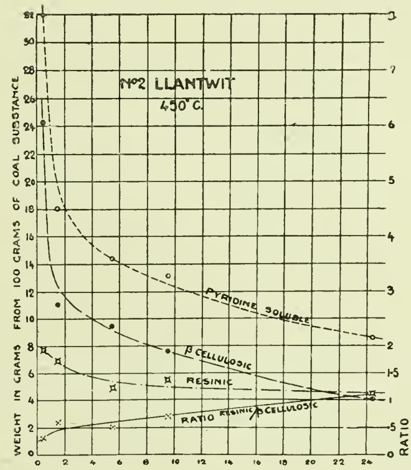



Fig. 9.

the general similarity of behaviour during the twenty-four hours' heating of this coal and the No. 3 Rhondda is evident. Residues arising from the two coals contained β cellulosic constituents associated with the resinic substances throughout the twenty-four hours' heating; the curves denoting the ratio of resinic to β cellulosic constituents in the residues are of the same type, and indicate a greater stability of the resinic

as compared to the $\beta$ cellulosic substances. The stability of these latter constituents are of the same order and markedly distinct from that of the corresponding portions of the Two Foot Nine seam and the No. 2 Rhondda. The No. 2 Llantwit undoubtedly decomposes at a faster rate in the earlier stages than does the No. 3 Rhondda. The percentage loss of constituents is detailed in the following Table :

Table XXII.—Percentage Loss of Constituents based on the Content of the $\frac{1}{2}$-hour Residue, No 2 Llantwit, at 450° C.

| Period (Hours). | Per Cent. Loss. | | |
|---|---|---|---|
| | Pyridine Soluble. | $\beta$ Cellulosic. | Resinic. |
| $1\frac{1}{2}$ . . . . | 43·63 | 53·74 | 9·47 |
| $5\frac{1}{2}$ . . . . | 54·92 | 60·84 | 36·14 |
| $9\frac{1}{2}$ . . . . | 58·80 | 68·55 | 28·25 |
| $24\frac{1}{2}$ . . . . | 73·16 | 83·32 | 41·50 |

These figures are represented graphically in Fig. 10, from

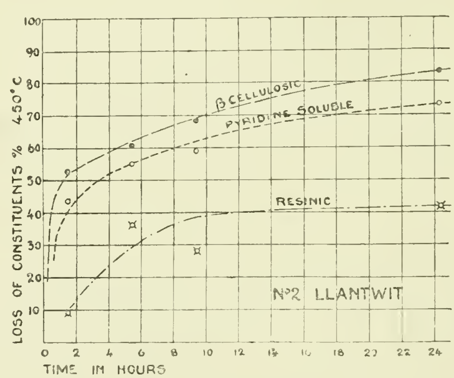



Fig. 10.

which definite points of flexure are evident in the curves for both the resinic and $\beta$ cellulosic substances. The $\beta$ cellulose

appears to consist of two types of substance in equal amounts, and compared to that of the No. 3 Rhondda this constituent is less stable, since it is decomposed to a 10 per cent. greater extent for the same duration of heating than pertains in the case of the latter coal. The stable portion of the resinic substances is more stable than the stable resin of the No. 3 Rhondda; it represents a resin practically stable at 450° C. Subsequent results of this investigation reveal a marked difference in property of these two types of resin.

Analyses of resinic substances isolated from various residues are given in Table XXIII.

TABLE XXIII.

| Residue. | Original. | 5-hour, 450° C. |
|---|---|---|
| C. . . . . . | 83·37 | 84·53 |
| H. . . . . | 7·71 | 7·15 |
| O.N.S. . . . . | 8·91 | 8·32 |
| Ratio C/H . . . | 10·81 | 11·82 |

*Nitrogen and Sulphur:*

TABLE XXIV.—AMOUNTS OF NITROGEN AND SULPHUR PRESENT IN THE RESIDUES FROM 100 PARTS OF COAL SUBSTANCE, NO. 2 LLANTWIT, AT 450° C.

| Duration of Heating (Hours). | Per Cent. Nitrogen. | Per Cent. Sulphur. |
|---|---|---|
| Original . . . . | 1·49 | 2·08 |
| 1 . . . . | 1·40 | 1·72 |
| 2 . . . . | 1·39 | 1·56 |
| 5 . . . . | 1·42 | 1·40 |
| 24 . . . . | 1·38 | 1·22 |

These results show that a nitrogenous substance is decomposed in the early stages of the decomposition of the coal substance. Constituents containing 'organic' sulphur are

undergoing decomposition throughout the whole period of decomposition.

### Examination of Stability of β Cellulose and Resinic.

*No. 2 Llanwit at* 350° *C.*

The examination of the residues resulting by heating charges, the No. 2 Llantwit at 350° C. and the No. 3 Rhondda at 400° C., for various intervals of time was next undertaken, with a view to determine with greater exactitude the difference in stability of the β cellulose relative to the resinic constituents in each of these coals. The following results were obtained, from which were calculated the amounts of the constituents present in the residue resulting from 100 parts of coal substance.

Table XXV.—Amounts of Constituents present in Residues obtained from No. 2 Llantwit at 350° C.

| Duration of Heating (Hours). | Per Cent. in Residue. | | | Amount in Residue *ex* 100 Coal Substance. | | |
|---|---|---|---|---|---|---|
| | Pyridine Soluble. | β Cellulose. | Resinic. | Pyridine Soluble. | β Cellulose. | Resinic. |
| $1\frac{3}{4}$ . | 23·74 | — | — | — | — | — |
| $2\frac{3}{4}$ . | 20·90[1]<br>21·79 | 12·47 | 9·32 | 22·55 | 12·90 | 9·65 |
| $4\frac{3}{4}$ . | 29·36 | 19·98 | 9·38 | 28·80 | 19·60 | 9·20 |
| $10\frac{3}{4}$ (a) . | 27·21 | | | | | |
| $10\frac{3}{4}$ (b) . | 27·C0 | 17·70 | 9·30 | 26·87 | 17·62 | 9·25 |

[1] On repeat of heating operation loss of weight = 2·11 per cent.

The anomalous results in the case of the residues resulting in the early periods of heating are rather remarkable. At first it was suspected that oxidation of the residue might be the cause. The total repetition of the determination for a period of two and three-quarter hours gave practically the same results. A similar anomaly is evident in the case of the No. 3

Rhondda at 400° C. The problem of the effect of various temperatures below the temperature of decomposition of the coal upon the amount of substance extractable from a coal is under investigation. Until this work is completed the anomalous behaviour may be explained as arising from the following causes : The amount of substance soluble in pyridine obtained from any coal that has been heated above its decomposition point is the resultant of two opposing factors. One due to the 'unbinding' of the coal structure results in an increase of soluble constituents. The other produces a decrease of pyridine soluble constituents by virtue of the destruction of substances which in the unheated coal are soluble in pyridine. The net result will depend upon the relative velocity with which these opposing factors operate, and should the latter factor be concerned with substances which decompose very rapidly it is evidence that its influence on the result may be the determinant. Whatever the subsequent explanation of these discrepancies may be, it is apparent from the above results that the $\beta$ cellulosic constituent is decomposed at a more rapid rate than the resin substances, which appear to be practically stable at this temperature. No doubt the portion of the $\beta$ cellulose here destroyed is that portion rapidly decomposed at 450° C.

These results reveal the fact that the $\beta$ cellulose is more readily decomposed than the resinic substances. It is interesting to observe that the amount of resinic substance found in the coal substance by direct extraction was equal to 14·07 per cent., that the half-hour residue at 450° C. contained only 11·21 per cent., whilst the $1\frac{3}{4}$ hour period at 400° C. contains 11·66, facts which indicate that at least two or three per cent. of the resinic substance is rapidly decomposed at the temperatures indicated. The increase of the value for the $\beta$ cellulose in the residues resulting from heating the coal for periods

up to $4\frac{3}{4}$ hours at 400° C. indicates that in all probability the 'unbuilding' of the coal substance renders an enhanced amount of $\beta$ cellulose soluble in pyridine. This is very unstable at 450° C., since the half-hour residue at this temperature only contains 19·93 per cent. It is hoped that work now proceeding on the extraction of the various coals by Hargers' method of heating the coal with pyridine at a temperature around 150° C. will give more reliable data as

*No. 3 Rhondda at 400° C.*

TABLE XXVI.—AMOUNT OF CONSTITUENT PRESENT IN RESIDUE OBTAINED FROM NO. 3 RHONDDA AT 400° C.

| Duration of Heating (Hours). | Per Cent. in Residue. | | | Amount in Residue *ex* 100 Coal Substance. | | |
|---|---|---|---|---|---|---|
| | Pyridine Soluble. | $\beta$ Cellulose. | Resinic. | Pyridine Soluble. | $\beta$ Cellulose. | Resinic. |
| $1\frac{3}{4}$ . | 32·53 | 21·23 | 11·30 | 32·86 | 21·46 | 11·66 |
| $2\frac{3}{4}$ . | 38·48 | 25·70 | 12·76 | 37·63 | 25·14 | 12·149 |
| $4\frac{3}{4}$ . | 36·60 | 23·60 | 13·00 | 35·60 | 22·96 | 12·64 |
| $10\frac{3}{4}$ . | 22·60 | 11·85 | 10·75 | 21·02 | 11·03 | 10·00 |

to the amounts of the various substances present in the coals. Whatever may be found to be the actual amounts of the constituents of the coal substance of these coals which are soluble in pyridine and separable by chloroform, the values obtained for the various half-hour residues are shown by the experiments now to be described to constitute a definite basis for the discussion of the various series of results at 450° C. and their bearing upon the coking qualities of the coals.

The following experiments were undertaken at 450° C. in order to determine if the decomposition of these coals was in conformity with the results obtained by Dr. Wheeler with other coals, namely, that decomposition of a coal at temperatures

below 500° C. was concerned with the destruction of the pyridine soluble substances. That portion of the half-hour residue (450° C.) insoluble in pyridine was washed repeatedly with dilute hydrochloric acid, and then with water until it was free from acid. The washed residue was dried for eight hours at 105° C. in vacuo. One gramme of the residue was then weighed out into a porcelain combustion boat and heated at 120° C. for one hour in a current of dry nitrogen, cooled in nitrogen, and the loss of weight determined. The boat and its contents were next heated at a temperature of 450° C. in a current of nitrogen for three hours. The products involved from the residue were swept forward through an absorption train containing a known volume of standard acid. The boat and its contents were cooled in nitrogen and weighed, and the loss of weight determined. The acid in the absorption train was then titrated with N/5 ammonium hydrate, using cochineal as an indicator, and the amount of acid neutralised then determined. Other workers have drawn attention to the fact that in all probability pyridine combines with the coal substance. A very pronounced smell of pyridine was observed in blank experiments at 450° C., moreover a solution in water of the vapours involved gave a distinct precipitate with picric acid, consequently the equivalent of the acid neutralised was calculated in terms of pyridine. The results obtained with the various residues are given in Table XXVII.

The individual coals yielded no products soluble in aqueous caustic potash (10 per cent.), and hence no ulmin compounds are present in these coals. The above results show that after removal of that portion of the residue soluble in pyridine the resulting residue of the No. 2 Llantwit heated to 450° C. contains only a small amount of products decomposable at 450° C. The higher volatile figure for the two-hour residue is attributable to the causes suggested above, namely, that

all the $\beta$ cellulosic constituents are not rendered soluble or are not produced as a secondary product by the preheating at 350° C. for two hours. It is interesting to note the close agreement between the pyridine content of the two residues from this coal, a fact which indicates a similarity of chemical nature of that portion of these residues stable at 450° C., and it constitutes direct evidence of the union of pyridine with

TABLE XXVII.—PERCENTAGE PYRIDINE AND VOLATILE MATTER EVOLVED AT 450° C. FROM THE RESIDUES FROM THE PYRIDINE EXTRACTION OF 'COKES.'

| Residue. | 1 hour Loss at 120°. | Volatile 450° C. | Pyridine evolved 450° C. | Equivalent Volatile in Original Coal. |
|---|---|---|---|---|
| ½ hour, 450° C. No. 2 Llantwit . | 0·50 | 10·21 | 7·56 | 1·41 |
| 2 hours, 350° C. No. 2 Llantwit . | 0·50 | 18·26 | 7·75 | 8·21 |
| ½ hour, 450° C. No. 3 Rhondda . | 0·58 | 9·35 | 3·14 | 4·14 |
| ½ hour, 450° C. No. 2 Rhondda . | 0·31 | 1·64 | 1·41 | 0·12 |

the coal substance. Moreover, the decrease in 'acidity' of the corresponding portions of the other coals is evident from the decrease in the amounts of pyridine in the residues. The high volatile figure of the half-hour residue of the No. 3 Rhondda may be due to the same causes as the higher volatile figure of the 350° C. residue of the No. 2 Llantwit, as compared to the 450° C. residue from the same coal. The No. 2 Rhondda from the above results yields its maximum pyridine soluble after the half-hour heating at 450° C., and contains no other constituents decomposable below 450° C.

It is evident from the above results that in the study of the decomposition of the coals concerned at temperatures below

450° C. the major portions, if not all the constituents undergoing change are those soluble in pyridine, and further that the volatile matter expelled from any coal during a given period at 450° C. may be regarded as arising from the destruction of the pyridine soluble substances.

The individual curves representing the decomposition at

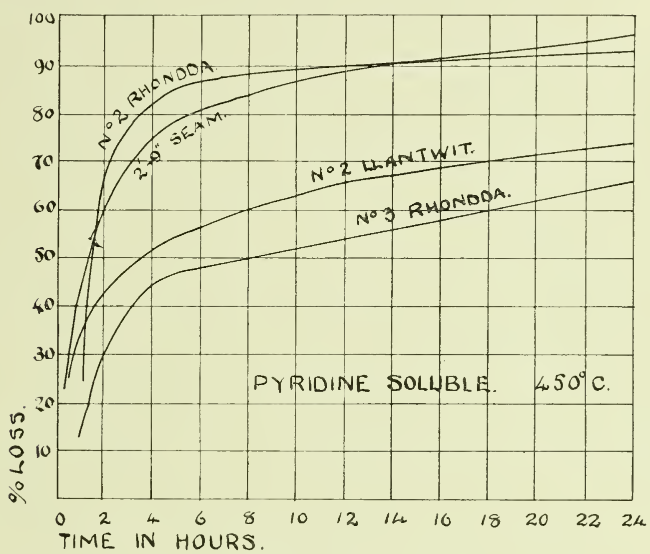



Fig. 11.

450° C. of the pyridine soluble, $\beta$ cellulosic, and resinic constituents of the several coals are grouped in Figs. 11, 12, and 13 respectively, from which the general relative ease of decomposition of these constituents becomes evident.

The main results of this investigation are as follows :

(1) The decomposition of the coals at temperatures up to 450° C. results in the destruction, as such, of the pyridine soluble constituents of the coal substance.

(2) The stability of the pyridine soluble constituents in the coals examined is in the following order of decreasing stability (see Fig. 11) :

No. 3 Rhondda.
No. 2 Llantwit.
Two Foot Nine.
No. 2 Rhondda.

(3) The decomposition of the pyridine soluble constituents results in a more rapid decomposition of the $\beta$ cellulosic

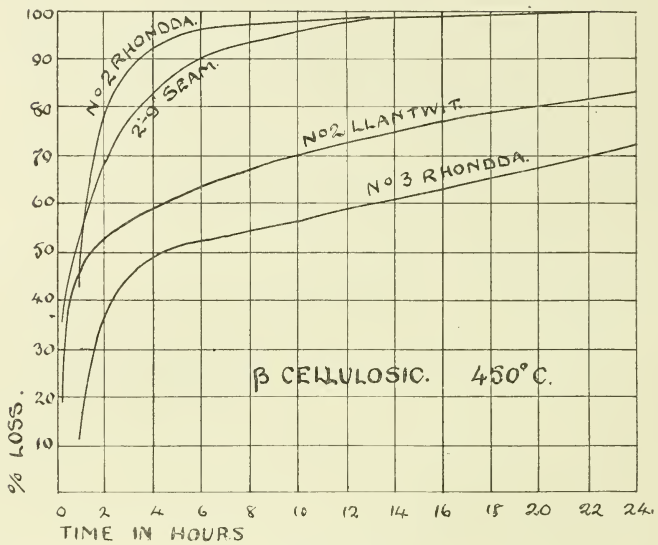



Fig. 12.

substances than of the resinic compounds. In all probability the $\beta$ cellulosic constituents are the first to decompose.

(4) Two types of $\beta$ cellulosic and resinic compounds occur in each of the coals examined: (*a*) one type is readily decomposed at 450° C., (*b*) the other type is comparatively stable at this temperature.

(5) The typical coking coals contain an approximately homogeneous $\beta$ cellulosic class of substance readily decomposed at 450° C., whilst the other coals examined contain nearly equal amounts of the two types enumerated under (4). See Fig. 12.

(6) The facts enumerated in paragraph (5) are generally characteristic of the resinic substances in these coals, although the homogeneity of the resins is not so well marked in the true coking coals. See Fig. 13.

(7) The stability of the $\beta$ cellulosic relative to the resinic compounds is more pronounced in the No. 3 Rhondda and No. 2 Llantwit than in the typical coking coals.

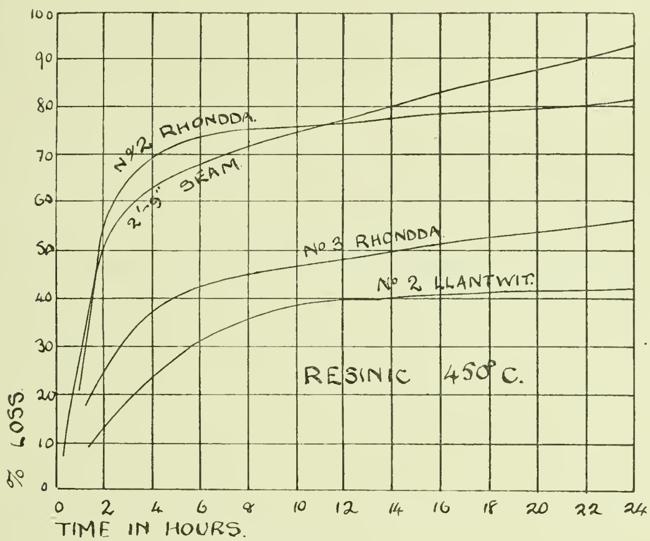



Fig. 13.

(8) The progressive decomposition of the $\beta$ cellulosic and resinic substances in the case of the coking coals results in a rapid increase of the ratio, the amount of resinic constituents to the amount of $\beta$ cellulosic. In the other coals the increase of this ratio is very gradual.

(9) Progressive destruction of the coal substance at temperatures not exceeding 450° C. ultimately results in a residue devoid of $\beta$ cellulosic substance, but one which still contains resinic bodies.

(10) Nitrogenous bodies in the coal are destroyed at

450° C.; the nitrogen eliminated represents approximately 10 per cent. of the total nitrogen present in the coal.

(11) Sulphur compounds are more readily decomposed in the highly bituminous than in the lesser bituminous coals, certain of which do not evolve volatile sulphur compounds at 450° C.

## PART II.—An Investigation of Coking Coals.

The various theories that have been advanced from time to time to explain the phenomena accompanying the production of coke from coal are passed under review in Chapter 8 of the late Professor Lewis's book 'The Carbonisation of Coal' (1912). Professor Lewis states: 'Most observers look upon the luting body in the coal as tar residues.' Wedding differs from this view, and attributes the production of coke to the deposition of carbon within the mass of coal by virtue of the destruction of gaseous hydrocarbons. Lugi, Donath, and others consider that the production of a coke is due to internal change in the nature of the carbon molecule. Professor Lewis advanced the opinion that the formation of coke arises from the successive deposition and decomposition of the heavy tars from layer to layer of the charge. The distillation of the heavy tars and the subsequent decomposition thereof is due to the gradual flow of heat from the hot oven walls into the charge. Anderson (*Jour. Soc. Chem. Ind.*, 1896) ascribes the coking qualities of a coal to the presence in the coal substance of resinic bodies, and from the different behaviour of certain Scotch coals under the action of caustic soda, together with the different stabilities of these coals at 300° C., he divides the resins into two classes: (*a*) one class decomposed below 300° C. and saponified or oxidised by caustic soda, (*b*) a class of resinic substance stable above 300° C. and not altered by caustic soda. Wheeler and Stopes in their monograph on

the 'Chemistry of Coal' (page 9) make the following comment on Anderson's work: 'The compounds extractable by alkaline solutions are undoubtedly ulmin compounds, . . . moreover their presence in coals has been shown to exert a detrimental effect on the coking properties of the coal.' Anderson's views must therefore be considered as not fundamentally based upon conclusive evidence as to the nature and properties of the resinic substances in coal. Finally, Bedson in 1900 showed that the cementing principle in certain coals was capable of extraction by pyridine, a view that was subsequently enlarged by Wheeler when he showed that the pyridine soluble portion of a coal could be separated by extraction with chloroform or benzene into two portions, only one portion of which, the resinic or gamma compound, was possessed of coking qualities. Any endeavour to formulate a theory of coking must take into account not solely the mere formation of a coke, but in addition some light must be shed on the variations of strength, porosity, etc., of the cokes from different types of coals.

The differences in behaviour of the four coals dealt with in the author's paper, 'The Decomposition of Coal under the Influence of Low Temperatures, . . .' cast considerable light upon the fundamental causes influencing the nature of the cokes resulting from various coals. The four coals investigated were as follows:

The No. 2 Llantwit is gas coal, and gives rise to a porous coke.

The No. 3 Rhondda in actual oven practice yields a dense coke which is inclined to be brittle.

The No. 2 Rhondda is a typical coking coal, and furnishes a good metallurgical coke.

The Two Foot Nine from the South Crop also belongs to that class of coal which produces metallurgical coke.

The coal substances can be split into three types of substance by the 'pyridine-chloroform' method of extraction. In conformity with the observations of Wheeler, Bedson, and others it was observed that only the resinic constituents of the coals

TABLE XXVIII.—THE COKING PROPERTIES AND PERCENTAGE VOLATILE OF RESIDUES FROM THE VARIOUS COALS.

| Residue. | Temperature of Formation. | Per Cent. Volatile in Residue, 950° C. | Per Cent. Resinic Substances in Residue. | Nature of Coke. |
|---|---|---|---|---|
| | | *No. 2 Llantwit.* | | |
| Hours. | °C. | | | |
| ½ . . | 450 | 35·10 | 7·56 | Dense, hard coke. |
| 1½ . . | 450 | 24·30 | 7·37 | Do. |
| 3½ . . | 450 | 24·00 | — | Very weak coke, scarcely coked, much detritus. |
| 5½ . . | 450 | 24·10 | 5·33 | |
| 9½ . . | 450 | 23·20 | 5·63 | Do. |
| 24½ . . | 450 | 21·00 | 4·00 | No coke. |
| 4¾ . . | 350 | 32·00 | — | Dense, hard coke. |
| 10¾ . . | 350 | 30·85 | 9·30 | Do. |
| 10¾ . . | 400 | — | — | No coke. |
| | | *No. 3 Rhondda.* | | |
| 1½ . . | 450 | 21·63 | 9·86 | Dense, hard coke. |
| 3½ . . | 450 | 21·79 | 7·58 | Do. |
| 5½ . . | 450 | 21·65 | 5·30 | Dense coke. |
| 24½ . . | 450 | 19·40 | 5·73 | Coked, a little detritus. |
| | | *No. 2 Rhondda.* | | |
| 1½ . . | 450 | 20·51 | 7·99 | Dense coke. |
| 2½ . . | 450 | 14·56 | 5·01 | Coked, much detritus. |
| 5½ . . | 450 | 12·98 | 3·12 | No coke. |
| 12½ . . | — | 11·40 | 2·60 | Do. |
| | | *Two Foot Nine.* | | |
| 1½ . . | 450 | 19·18 | 8·62 | Dense, hard coke. |
| 2½ . . | 450 | 16·70 | 6·36 | Do. |
| 5½ . . | 450 | 16·10 | 4·51 | Coked, much detritus. |
| 24½ . . | 450 | 14·82 | 1·12 | No coke. |

examined left a coherent residue when carbonised at temperatures varying from 450° C. to 900° C. Intimate mixtures of any two of the three components of the coals proved that only those mixtures containing the resinic substances were capable of giving a residue of a coherent nature at 900° C. Consequently, solely to the resinic portions of a coal must be ascribed the property of causing the cohesion of a coal into a coke when carbonisation takes place. The investigation of the decomposition of the coals at 450° C. proves that under the continued influence of this temperature there results a progressive destruction of the resinic portion of the coal substance and the production of residues containing decreasing quantities of this type of substance. The residues obtained during the course of the investigation of the coals were ground up to the same degrees of fineness, and one gramme was heated at 900° C. under standard conditions in order to determine if a coke was produced from the residue. The minimum amount of resinic substances necessary for the production of coke must lie between the amounts present in that residue which, produced by the shortest period of heating, fails to yield a coke and the amount in the residue anterior to it in series which does coke.

The above results indicate a difference in the cementing properties of the various resinic bodies contained in the different coals; those constituents contained in the No. 2 Llantwit have a weaker coke producing quality than the others. The minimum amount of resinic substance in the residues from the various coals necessary to be present in order that they yield a coke lies between the following limits:

| | | | | | |
|---|---|---|---|---|---|
| For the | No. 2 Llantwit . | 6·00 | per cent. to | 7·00 | per cent. |
| ,, | No. 3 Rhondda . | 5·30 | ,, ,, | 5·70 | ,, |
| ,, | No. 2 Rhondda, about | 5·00 | ,, | | |
| ,, | Two Foot Nine . | 4·50 | ,, ,, | 6·36 | ,, |

The mean figure for the majority of the coals is not far removed from 5·5 per cent., but in this generalisation the reservation must be made that in all probability for those coals containing less than 84 per cent. of carbon in the coal substance this figure will tend to increase.

The investigation detailed in Part I. has led to the formulation of a new theory of coking, which will be first enunciated, and subsequently the facts upon which it is based will be indicated. It has been shown from the results detailed in Part I. relative to the behaviour of the various coals at different temperatures that every coking coal is characterised by a fairly well marked temperature at which coking commences. The view is held in agreement with Anderson that all coking coals soften and become plastic, but I regard this temperature as not far removed from 400° C. The $\beta$ cellulosic constituent of the coals examined by Wheeler (*Jour. Chem. Soc.*, 1910) were devoid of any tendency to melt or soften, but he found that the resinic substances melted at 150° C. Observations on the coals examined in the present research reveal the same characteristics of the two cellulosic types of substance, and confirm the fact that the resinic bodies readily melt at 200° C. and become practically fluid at 350° C. in an inert atmosphere. The plasticity of the coal is therefore attributed to the liquidation of the resins with heat, and the subsequent flow of the fluid or semi-fluid resinic matter around the other solid ingredients of the coal; maybe a definite absorption of the liquid resins by the other solid constituents takes place. The degree of plasticity in a coal is conditioned by the following factors:

(*a*) the amount of resinic matter present;

(*b*) the melting-point and the point of complete fluidity of the resinic constituents;

(*c*) the temperature to which the coal is subjected ;

(*d*) the proximity of that temperature to the point of decomposition of the resinic constituents.

The greater the amount of 'resinic' substance present, the more plastic the coal will become : too great an amount of resinic substance will result in a 'molten' coal capable of flowing like a liquid. The initial cementation into a coke of the residues arising from the destruction of the constituents

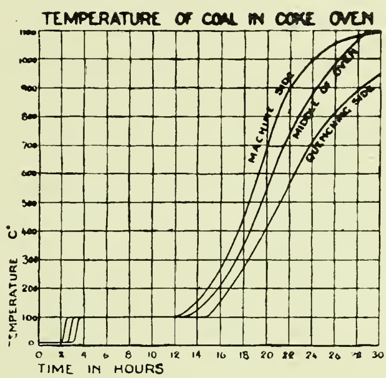



Fig. 14.

of a coal is due to the skeleton of carbon deposited between the non-melting ingredient by decomposition of the resinic substances.

The process of coking consists of the decomposition of the various substances in the coal, with the evolution of volatile matter and the formation of a very highly carbonaceous residue. The decomposition must take place in the order of the thermal stability of the substances in the coal, for in the modern type of coke oven there exists a very gradual temperature gradient between the hot walls of the containing vessel and the centre of the charge. The curve in Fig. 14 is constructed from the measurements of the temperature (originally made by Summersbach) at various places in a coke-oven and detailed

on page 335 of the first edition (1916) of Wagner's 'Coal and Coke.'

No doubt during certain intervals of time several substances are simultaneously undergoing decomposition, due to the temperature gradient in the oven increasing at a more rapid rate than permits of fractional decomposition of the coal substance. The early stage in the carbonisation of a coal comprises, as the above results have shown, the destruction of the resinic and $\beta$ cellulosic substances, and consequently that phase of carbonisation taking place at temperatures below, say, 500° C. is the phase concerned with destruction of plasticity in the hot mass of coal. As a generalisation 5·5 per cent. is the minimum amount of resinic matter necessary in a coal for the formation of a coke, and since the passage through various degrees of plasticity is a characteristic feature of coking coals under the influence of heat, 5·5 per cent. of resinic substance may be taken as the minimum amount necessary to render a coal mass plastic. Throughout the period that a coal undergoing decomposition contains above 5·5 per cent. of resins the resulting plastic mass will tend to be forced into a spongy state by virtue of the internal pressure resulting from the generation within the mass of gaseous and other products volatile at the existing temperature. The progressive destruction of the resin substances results in a change of the hot coal from the state of initial maximum 'fluidity' through increasing degrees of 'viscosity,' the approach to a very viscous or semi-solid state, and finally the absence of any plastic nature due to the reduction of the resinic content of the mass below 5·5 per cent. of the residue. When the plastic mass is possessed of the greatest fluidity the volatile matter evolved will tend to pass through the mass and escape from it without forcing it into a spongy state, but as the whole becomes more viscous the volatile matter will tend to be retained within the mass

as isolated bubbles, and due to the pressure each exerts the semi-coke will be forced into a spongy form. There must ultimately arise a state of affairs not far removed from the stage at which the resinic substance in the residue has been reduced to some 5 or 6 per cent., under which the volatile matter is generating within a medium so viscous that it takes a very appreciable period for that portion capable of escaping against the resistance of the mass to escape. The next phase is the loss of plasticity by the mass due to destruction of the resinic substance. It will be readily appreciated that the structure of the coke will be fixed, since the final production of the carbon skeleton binding the mass into a rigid body has now taken place. Vesicles or pores will thus be formed in the coke, and their size will be conditioned by the pressure each occluded pocket of gaseous matter exerts on the semi-solid mass just prior to it losing the final low degree of plasticity. The fundamental consideration determining the degree of porosity of a coke according to the theory here advanced is first the number of gaseous bubbles occluded in the coal mass when the resinic content is in the neighbourhood of 5·5 per cent., and secondly the pressure exerted by the gaseous matter thus occluded. These two factors are both determined by the amount of volatile matter evolved from the coal substance in that period just penultimate to the decrease of the resinic matter to below 5·5 per cent. The volatile matter evolved in the early periods is of lesser importance as regards its influence on the porosity of the coke, since so long as the mass is decidedly plastic it can 'rise and fall' with any fluctuations in the evolution of gaseous substance; moreover, even if the volatile matter should force the coal into a spongy mass, such a mass would sink down as soon as the evolution of volatile matter had decreased.

It is not suggested that a coal becomes actually fluid during

carbonisation; the terminology of plasticity, etc., adopted in the above representation must be taken more as an analogy than as a dogmatic statement of physical state. The successive stages indicated are not visualised as ensuing throughout the whole mass of the charge at the same time, but as a cycle of events taking place from layer to layer of the charge in a direction parallel to the hot walls of the oven and conditioned by the rate of penetration of heat towards the centre of the charge. The fact that considerable pressure must exist within a coke is evident from the following figures, due to J. Parry and quoted by Professor Lewis in his book, 'The Carbonisation of Coal' (1912), p. 221.

Twenty grammes of coke of the following composition

| | |
|---|---|
| C . . . . . | 89·45 |
| H . . . . . | trace |
| $O_1N$ . . . . | 1·305 |
| S . . . . | 0·795 |
| Ash . . . . | 89·45 |

gave rise to 361·5 c:c. of gas after heating for $2\frac{1}{2}$ hours, and all told yielded 1117·2 c.c. of gas after $14\frac{1}{2}$ hours' heating. The gas evolved in the first $2\frac{1}{2}$ hours period contained

| | | | |
|---|---|---|---|
| $CO_2$ . . . . | 22·8 | per cent. | by vol. |
| CO . . . . | 13·4 | ,, | ,, |
| H . . . . | 50·0 | ,, | ,, |
| $CH_4$ . . . . | 13·8 | ,, | ,, |

The presence of methane in this gas is evidence of the occlusion of gases evolved at temperatures below 700° C., for Burgess and Wheeler (*Jour. Chem. Soc.*, 1910) state that paraffins cease to be produced above this temperature.

This theory of coking has arisen from consideration and extension of the work detailed in Part I. of this research; the underlying facts point out the salient features determining

the differences in the nature of the coke from the coals examined. The volatile matter evolved during any period of time at temperatures below 500° C. is the sum of the volatile matter arising from the resinic and $\beta$ cellulosic components undergoing decomposition. The resinic constituents are the source of the substance which cements the various residues from the coal substance into a coherent coke; associated with the formation of the 'cement' is the evolution of a definite amount of volatile matter derived from the resinic substances undergoing degredation to carbon. This volatile matter *per se* must result in the production of porosity in the coke, the degree of which is determined by the amount of volatile matter evolved in the period just prior to the destruction of coking qualities in the layer of coal considered during the period of time when the resinic content of the semi-carbonised mass is between 5 and 6 per cent.

Some indication of the difference in the amount of volatile matter evolved at various temperatures from the resins in certain of the coals examined is evident from the following table, the values in which were determined by heating one gramme of the resin at the specified temperature for seven minutes in a platinum crucible.

TABLE XXIX.—PERCENTAGE VOLATILE OF RESINS AT VARIOUS TEMPERATURES.

| Coal. | 425° C. | 600° C. | 950° C. |
|---|---|---|---|
| No. 2. Llantwit . | 29·43 | 60·03 | 81·04 |
| No. 3. Rhondda . | 8·90 | 56·00 | 69·45 |
| No. 2. Rhondda . | 12·87 | 54·00 | 64·21 |

The marked difference in 'volatility' of the resinic constituents of the No. 2 Llantwit and the No. 3 Rhondda is very evident; it constitutes a characteristic difference in

property of the resins in the gas and coking coals. The greater volatile figure at the lower temperature, taken into account with the fact that of the coals examined the No. 2 Llantwit is the only one to decompose to any great extent at 350° C., offers some explanation of the greater porosity of the coke from this coal, but other facts are yet to be considered. The previous results have shown that the true coking coals contain an apparently homogeneous $\beta$ cellulosic constituent which is decidedly more unstable than the resinic constituents in these coals, and it is practically destroyed in the first three hours of carbonisation at 450° C. On the other hand, the gas coals contain a $\beta$ cellulosic substance of the same order of stability as their resinic constituents, and it is associated to a considerable extent with the residual resinic remaining in the coal at the expiration of long periods of carbonisation at 450° C. The true coking coals lose their $\beta$ cellulosic constituents as such in the very early periods of coking, when the coal is still possessed of considerable plasticity and the volatile matter arising from the decomposition of this type of substance is able largely to escape from the mass. The result is that during the critical period of carbonisation the viscous coal mass is only under the leavening influence of the volatile matter evolved from the resinic substance, an amount much smaller than that evolved from the resinic substance of the gas coals, hence the texture in the case of the coking coal is of a more compact nature than that arising under similar conditions from the gas coals. Due to the greater stability of the $\beta$ cellulose in the gas coals and to its resultant association with the resinic matter throughout long periods of carbonisation at 450° C., the coal mass of the gas type of coal is during the critical period not only under a greater leavening influence arising from the greater amount of volatile matter evolved from the resins themselves, but added to this

must be the effect of the volatile matter evolved from the $\beta$ cellulosic substance remaining in the semi-coke and undergoing decomposition concurrently with the resinic substances. The greater stability of the $\beta$ cellulosic and higher yield of volatile matter from the resinic substance is one of the chief causes of the porosity of the cokes from the gas type of coals.

Fig. 15 depicts the curve showing the variation of the ratio of resinic to $\beta$ cellulosic constituents in the various residues derived from the coals investigated. It is interesting to note the rapid rise towards the maximum of these curves for the true coking coals compared to the very slow rise of the curves for the gas coal. Facts due to the greater relative stability of the $\beta$ cellulose in the latter type of coal:

Table XXX.—Percentage Volatile $\beta$ Cellulosic Constituents at Various Temperatures.

| Coal. | 425° C. | 600° C. | 950° C. |
|---|---|---|---|
| No. 2 Llantwit . | 14·04 | 26·83 | 37·45 |
| No. 3 Rhondda . | 10·08 | 22·16 | 27·01 |
| No. 2 Rhondda . | 9·42 | 14·81 | 28·69 |

The results in the above table were obtained in the same manner as the results given in Table XXVII. The greater amount of 'volatile' evolved at the lower temperature in the case of the No. 2 Llantwit is a feature that still further increases the tendency of this coal to produce a porous coke. The sum of the volatile matter evolved during any interval of time by decomposition of resinic and $\beta$ cellulosic material in the coal is actually the volatile matter evolved from that portion of the coal substance soluble in pyridine and decomposed in the interval of time considered. This figure

can be determined, since it is the loss of weight of the coal substance in any period divided by the decrease of pyridine

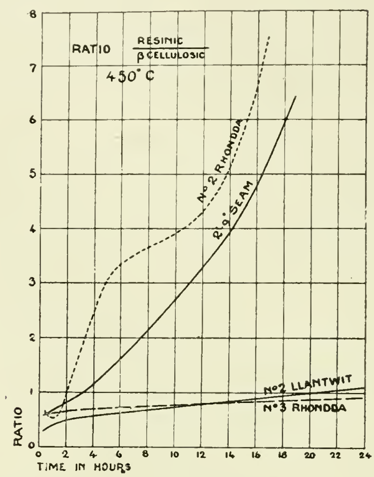



FIG. 15.

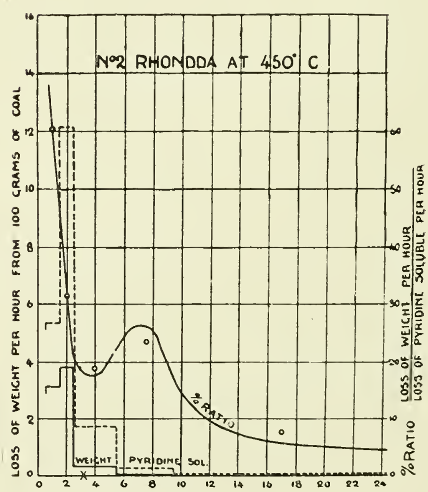



FIG. 16.

soluble constituents in that period. The loss of weight of the coal substance for the various coals in any given period

is readily obtained from the data detailed in Table VIII., whilst the corresponding amount of the pyridine soluble substance destroyed can be obtained from Tables IX., XIII., XVII., and XXI. The percentage ratio figures thus obtained are for brevity termed the 'period volatile.'

The loss of weight and the loss of pyridine soluble substance per hour per 100 grammes of coal substance are represented for each coal in Figs. 16–19. From these results the ratio curves

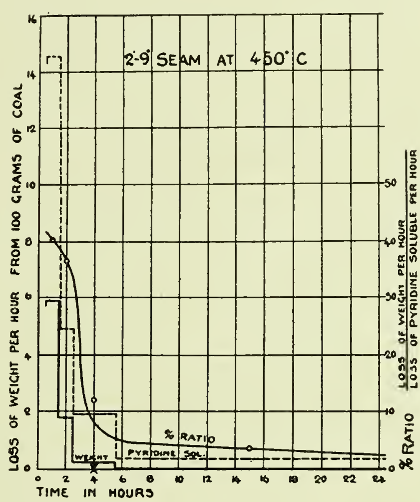



Fig. 17.

have been constructed. These ratio curves for the various coals are collected together in Fig. 20, and it is readily apparent that the order of the coal as regards the amount of volatile matter yielded at any instance by the decomposition of the pyridine soluble substance is as follows :

No. 3 Rhondda.
No. 2 Llantwit.
No. 2 Rhondda.
Two Foot Nine Seam.

These curves, be it noted, reach a maximum value which occurs in the early period of heating in the case of the

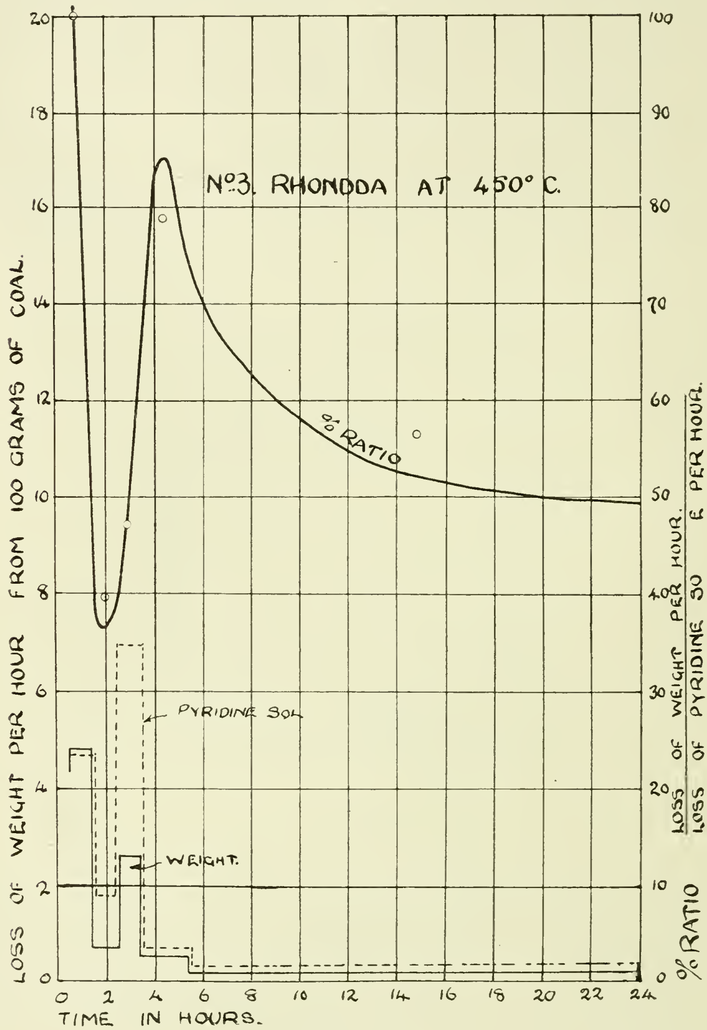



FIG. 18.

coking coals, and the curves for this type of coal rapidly fall towards a minimum value. The crucial characteristic of any coal as regards the porosity of the resulting coke is the amount of 'volatile matter' evolved when the hot mass is in its most

viscous state and about to pass, by virtue of destruction of the resins, to a fixed structure.

In the case of the No. 2 Llantwit this change occurs between 3½ hours' and 5 hours' heating at 450° C., in all probability at the end of 4 hours' heating. Reference to Fig. 19 shows that at this time the volatility of the pyridine soluble substances undergoing decomposition approaches the maxi-

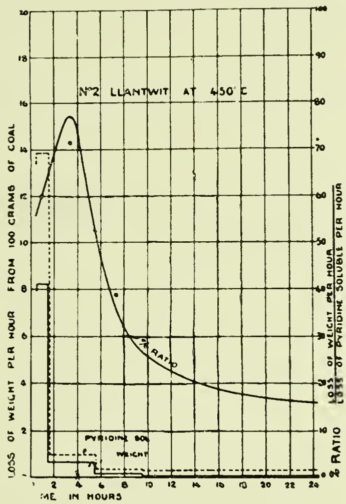



Fig. 19.

mum, and hence the viscous mass just prior to fixation of form is under the influence of the maximum leavening effect that arises from this coal. The destruction of coking qualities in the Two Foot Nine and No. 2 Rhondda occurs after 4½ and 2½ hours' heating at 450° C. respectively, at which time the percentage of the volatile matter evolved from the pyridine soluble substance undergoing change is seen from Figs. 16 and 17 to be far removed from the maximum value, and approximating towards the minimum value. Hence the leavening influence in this type of coal is comparatively small.

The effect of leavening effect during the critical stages is the total volatile matter evolved during this period, the

value of which from 100 parts of coal substance can be calculated at any instance, by multiplying the amount of pyridine soluble substance undergoing decomposition by the volatile of the substances decomposed at the instance considered.

The values for the No. 2 Llantwit, Two Foot Nine, and No. 2 Rhondda at their critical period are arrived at by reference to Figs. 16, 17, and 19, from which the total volatile matter evolved during the critical period has been calculated.

Table XXXI.—Leavening Effect based on 100 Parts of Coal Substance at Critical Periods.

| Coal. | Pyridine Soluble. Loss Weight per Hour. Grammes. | Volatile from Pyridine Soluble. Per Gramme. | Total Volatile per Hour. Porosity Factor. |
|---|---|---|---|
| No. 2 Llantwit . | 1·0 | 0·73 | 0·73 |
| No. 2 Rhondda . | 1·8 | 0·18 | 0·32 |
| Two Foot Nine . | 1·9 | 0·03 | 0·16 |
| No. 3 Rhondda . | 0·2 | 0·45 | 0·09 |

The figures in column 3 of the above table are termed the 'Porosity Factor,' and it is interesting to note that the numerical value of the factors for the individual coals are in the same order as the porosity of the cokes they give rise to.

The No. 3 Rhondda is intermediate in nature between the gas and coking coals. On an industrial scale it is utilised for both purposes. In many of the features so far discussed for the several coals this particular coal has behaved in a manner approaching the behaviour of the gas coals more than that of the coking coals, but it will now be shown that the No. 3 Rhondda has all the special characteristics peculiar to a true coking coal. The data given in Table XXVIII. shows that on the expiration of twenty-four hours' heating at 450° C. the coking qualities of this coal are not destroyed. The curves in

Fig. 11 indicate the greater relative stability of the pyridine soluble constituents of this coal. In addition the general

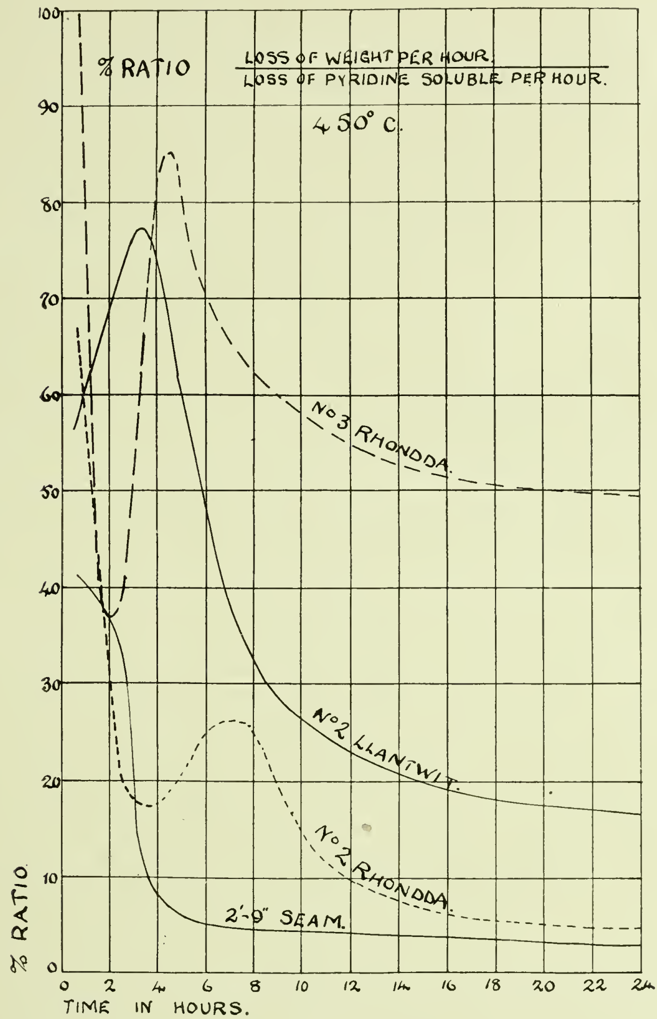



FIG. 20.

curvature of the curves in Fig. 9 leads to the conclusion that the $\beta$ cellulosic constituents will be wholly destroyed at the end of forty-eight hours' heating at 450° C.; at the expiration of

this time there will remain in the residue some 5–6 per cent. of resinic matter, an amount sufficient to cause the residue to coke. The critical period in the production of a coke occurs after a long lapse of time, and it is evident from the exterpolated results derived from the curves in Fig. 19 that during the critical phase the pyridine soluble constituents will be undergoing decomposition at a rate not exceeding the destruction of 0·2 grammes, per 100 grammes of coal substance, and that the volatile figure of the constituents destroyed will be 45 per cent. by weight. The porosity factor will thus have a value 0·09, which is lower than that for any of the coals considered, and hence the coke from this coal will be of a dense nature. The very low rate of decomposition of the resins in the coal, coupled with the resulting longer periods of time that the hot mass is in a plastic state, allows the volatile matter evolved to escape from the mass, and it is this long period of coke formation which nullifies the highly volatile nature of this coal and its propensity to result in a porous coke.

The theory of the causes of porosity in a coke is thus developed from experimental data. Attention is drawn to the four micro-photographs. These photographs were taken by direct illumination of the surface of the residues of the No. 2 Llantwit; each surface was first smoothed by gently rubbing it on fine emery paper, and finally brushing the prepared surface with a fine camel hair brush. The large vesicles and stream lines of the molten resins are evident in the one-hour and two-hour residues. The five-hour and twenty-four hour residues are devoid of large vesicles, individual particles of the charge are not evident, and the whole mass has settled down to a coke.

## *Hardness of Coke.*

The hardness of a coke is determined by two factors:

(*a*) The total amount of cementing material in the coke.

(*b*) The distention of the cementing material, *i.e.*, the volume over which it is dispersed, a factor conditioned by the porosity of the coke produced.

The initial cementing material in a coke results from the amount of fixed carbon left behind by decomposition of the resinic substance. The total hardening or cementing material is the initial material plus that amount of carbon subsequently deposited by the degradation of hydro-carbons, etc., at higher temperatures, say above 600° C. Work is at present proceeding in order to ascertain the maximum amount of resinic substance from the coals discussed. Meanwhile the maximum amount so far obtained is taken as a basis for the calculation of the initial cementing materials in the coals. This figure is obtained by multiplying the percentage of resinic bodies present by the amount of fixed carbon they yield when carbonised. The results are detailed in Table XXXII.

Table XXXII.

| Coal. | Percentage Resinic. | Fixed Carbons. | | | C. per 100 Coal Substance. | | |
|---|---|---|---|---|---|---|---|
| | | 425° C. | 600° C. | 950° C. | 425° C. | 600° C. | 950° C. |
| No. 2 Llantwit | 9·65 | 70·57 | 38·97 | 18·96 | 6·81 | 3·76 | 1·83 |
| No. 3 Rhondda | 14·07 | 91·10 | 44·00 | 30·55 | 12·81 | 6·19 | 4·3 |
| No. 2 Rhondda | 10·18 | 87·13 | 49·54 | 35·79 | 8·89 | 5·04 | 3·64 |

It is evident that the gas coals give rise to a smaller amount of initial cementing material at any temperature, and must hence produce a coke of weaker mechanical properties than the other coals. The initial cementing material, in my opinion, is the main cause of the hardness of a coke, for the amount of oil left behind and non-volatile at 450° C. in the various residues arising at this temperature never exceeded 1 per cent. by

weight of the coal. The above figures for the various temperatures indicate the reason for the brittleness of low temperature cokes, due to incomplete carbonisation of the resins. The thermal stability of the resinic substance influences the hardness, since a very gradual decomposition of these substances may result in the small amount of fixed carbon produced at one instant being disrupted by a rise in a semi-coked mass at a subsequent period. On the other hand, a rapid decomposition of resinic substance means a rapid fixation of structure, and will per interval of time produce more fixed carbon, a stronger structure, and one least liable to fracture by internal pressures arising during any subsequent interval.

The brittleness of certain batches of coke from the No. 3 Rhondda is to be ascribed to the periodical rising and falling of the semi-coked mass, resulting in the alternate formation and partial fracture of structure, a sequence of events very possible, since this coal contains a remarkably stable resinic substance, and the period volatile of the pyridine soluble constituents reaches a very high figure by comparison with the other coking coals. It is interesting to compare the views here developed with phenomena arising in actual practice. This aspect of the question will be developed at length in another communication, suffice for the moment to recall that the gases resulting in the very early stages of carbonisation are weak gases, poor in hydrocarbon and comparable in type to the gas obtained by Wheeler by distillation of $\beta$ cellulose.

The endeavour in actual practice to shorten the period of coking in ovens by increasing the temperature of the oven walls often results in the production of a porous coke from a coal which under normal conditions yields a good furnace coke. The higher temperature of the walls results in a steeper time temperature gradient in the oven, and a considerable shorten-

ing of the time during which the charge is under the influence of temperatures below 500° C. The relative stability of the $\beta$ cellulosic and resinic substances will be less differentiated the higher the temperature to which these substances are subjected, moreover the critical period of the charge will be shortened by the higher temperatures, and the result with higher flue temperatures will be that the fixation of structure in the coke will ensue nearer to the period of maximum 'period volatile' of the pyridine soluble substances, a fact which will produce a more porous coke.

Finally, it may be mentioned that arising out of this series of researches new processes have arisen that give every promise of bringing about the coking of coals at present unsuitable for production of metallurgical coke, improving the qualities of certain types of coal which yield inferior cokes under modern procedure, and thus materially enlarging our present gradually decreasing supply of coking coals; a class of coal essential to the iron and steel industry. The process has developed to the stage of large scale trials, and it has been provisionally protected; but I hope at no very distant date to deal with this aspect of the question before the Institute.

This investigation has been carried out in the Chemical Department of the South Wales and Monmouthshire School of Mines, Treforest. I desire to tender my best thanks to the members of the Board of the School for the facilities so kindly provided. I beg to acknowledge the keen interest and ever ready help of Principal Knox in furthering the prosecution of this work in every possible direction. Particularly do I desire to place on record my great indebtedness to Mr. Robert Metcalfe of the Engineering Department for his valuable services in making various pieces of apparatus required in the work; especially do I wish to acknowledge the care and trouble he has expended in preparing the diagrams,

curves, and slides illustrating this paper, and his valuable aid in analysing and discussing the experimental curves obtained. In a word, I am indebted to Mr. Metcalfe for his unfailing help in many directions.

It is evident that this work demands the investigation of many problems arising out of it, the extension of the investigation both in the direction of submitting the coals here considered to the influence of higher temperatures, and the investigation of a greater number of coals along the lines indicated.

As far as time permits such investigations along with other cognate problems are in progress, the results of which I shall place before this Institute from time to time.

## The Discussion.

The Chairman. Opening the discussion, the Chairman said he was not connected with the coking industry except indirectly, but he had listened with great interest to Mr. Illingworth's able exposition of the results of his investigation. The author of the paper had approached the subject from the scientific side, and, as he had said, the value of his scientific work had to be proved later on in commercial practice. During the last twenty years the coking of coals in South Wales had moved very rapidly. For many years only a few grades of coal in South Wales were deemed suitable for coking, which was done in a primitive type of oven. By steady investigation the number of coals it was possible to use for coking had been increased, and new types of coke-ovens had been adopted. They were being told on all hands that the salvation of the country lay in their own hands, and that economy in every industry was essential. Some people went so far as to advise that the Government should order that no coal should be burnt except that which had passed through the oven, that the whole of the volatiles should

be used in some other way and not allowed to pass in smoke up their chimneys. In these conditions the paper of Mr. Illingworth came at an opportune time. In a recent report—an abstract of which was published in the *Journal of the Society of Chemical Industry*—the Nitrogenous Products Committee had shown the economy of coking as against the direct use of raw coal. The coking of coal for metallurgical purposes and the recovery of volatile products for various uses were questions that were interwoven, and in South Wales they formed a most important feature of the coal industry. **The Chairman.**

Mr. H. E. Cox said the author of the paper had told them that the higher the amount of oxygen in coal the less was the coking value of the coal. Also, that coking was mainly a function of the resinic constituents. Perhaps Mr. Illingworth would explain in what way the oxygen was connected with the resinic constituents. **Mr. H. E. Cox.**

Mr. Illingworth said the oxygen in coal was largely a constituent of the $\beta$ cellulosic and humic substances, which *per se* did not furnish an important contribution to the 'coking principle' of coals; a high oxygen content in a coal would indicate in the present state of our knowledge a large amount of the constituents which lead to porosity and weak cokes. **Mr. Illingworth.**

Mr. J. H. Duncan said the paper was a mass of carefully collected information which they must wait to see in print before attempting to digest and criticise it. At this stage, however, he might ask Mr. Illingworth how much coal was taken for his samples, and how long it took to heat up to a maximum of 450°. Another point upon which he would like information was as to the high percentage of sulphur present in the pyridine extract. He (the speaker) supposed the whole of that sulphur arose from the organic substance. Mr. Illingworth also mentioned the presence of pyridine in the extracted residue and not in the pyridine extract. Did this show that **Mr. J. H. Duncan.**

Mr. J. H. Duncan.

part of the original nitrogen of the coal was there, or that it was due to the pyridine itself ? He would further like to know whether any examination was made of the gases evolved and their temperature when these tests were made.

In reply to Mr. Duncan,

Mr. Illingworth.

Mr. ILLINGWORTH said in the paper he had stated that the charge in each case was 25 grammes exactly. As regarded the time taken to stabilise, the period at 450° was half an hour ; at 400°, 40 minutes ; and at 350°, 45 minutes. With respect to the sulphur content in the pyridine extract, that sulphur must be organic sulphur.

Powell and Parr in a recent communication (*Bulletin III*, University of Illinois) had also shown the presence of sulphur in the resinic portion of certain coals. It was evident from the results detailed in his paper that pyridine combined with the *a* cellulosic (unsoluble) portions of coal. No doubt a large portion of the original nitrogen in the coal remained in this residue, for the researches detailed revealed only about 10 per cent. of the nitrogen eliminated from the coal when heated to 450°, and the nitrogen so eliminated must be an integral part of the pyridine soluble constituents of the coals. The present communication was only a commencement of a wide programme of research; the question of the gases evolved had been borne in mind but not investigated ; this aspect of the question had been developed independently by Dr. Wheeler and also by Porter and his co-workers. The gases might be mainly secondary products, and their examination would not furnish reliable data as to the underlying changes taking place in a coal during carbonisation.

Mr. J. H. Duncan.

Mr. J. H. DUNCAN asked whether in heating coal to 450° Mr. Illingworth had tried to make an extract with any other auxiliary than pyridine ? Had he tried chloroform, and was any tar abstracted after 450° ?

Mr. Illingworth said he washed the coal with carbon-chloride, and there were a certain number of oils, not volatile, at 450°. It had been shown that a certain number of substances could be extracted after reheating with chloroform or benzol actually boiling.

Mr. Illingworth.

Mr. J. Dyer Lewis, President of the South Wales Institute of Engineers, said he had listened with great interest to Mr. Illingworth, although not himself a chemist. The paper contained most valuable information, and its copiousness of detail must have entailed an enormous amount of care and patience on the part of its author in conducting his investigation. One important direction in which the paper led their thoughts, whether chemists or not, was as to the conservation of coal. There was no doubt they were faced with the absolute necessity of far greater economy in that respect than they had hitherto exercised. There was a great deal yet to be learnt in the recovery of by-products and in the method of coking and the utilisation of gases. More coal was burnt under boilers at their collieries than there ought to be by reason of the plant not being of a modern economical type. With regard to the coking of South Wales coals, he recalled that thirty-five years ago there were a great number of ovens between Pontypridd and Llwynypia, No. 3 Rhondda being considered the best coking coal in the market. Later on a better type of oven came to be adopted; and the late Mr. Archibald Hood, Llwynypia, actually crushed his No. 3 Rhondda large—which was perfectly clean and not damped in any way—and coked it. When he was an apprentice the Beehive oven was very largely used in the south outcrop coking Cribbwr Fawr and other seams of coal. In those days few people considered the chemical constituents of the coke; if it was bright and silvery it was deemed excellent coke. As President of the South Wales Institute of Engineers he welcomed Mr. Illingworth's important researches, and he

Mr. J. Dyer Lewis.

Mr. J. Dyer Lewis.

had pleasure in moving a cordial vote of thanks to that gentleman for his latest contribution, which he hoped to see in the Institute's 'Proceedings' as a sequel to that which had already appeared from his pen in those Transactions.

Professor Claude Thompson.

Professor CLAUDE THOMPSON seconded the vote of thanks. Like previous speakers, he said he hoped to have the benefit of reading the paper in print in order that he might digest the mass of information which Mr. Illingworth had put before them. He believed that the trouble which the author had taken would result in their obtaining a greater insight into what actually happened in the coking of coal.

The motion was carried by acclamation.

Mr. Illingworth.

Speaking in acknowledgment, Mr. ILLINGWORTH said like all other investigators he had experienced set-backs, but he was never discouraged. He was enthusiastically interested in his profession, although there was no harder taskmaster and no worse paid profession. If he was not an enthusiast he would have been in the Bradford wool trade. (Laughter.) If this country had to maintain its position in the world the chemist would have to be used to an infinitely greater extent than had been the case hitherto, and he would have to be much better paid if the best brains were to be employed. The fact was, in this country there had never been an organised endeavour for scientific industrial research. He was in the fortunate position at Treforest of having had the necessary apparatus provided for him, and of being afforded opportunities of prosecuting this work of trying to shed light on the scientific basis of the coking industry. But, as he had already indicated, there was work to be done in this investigation sufficient to keep ten chemists busily engaged upon its various aspects and developments. (Applause.)

# PROCEEDINGS.

## Cardiff University College Association of Engineering Students of the Institute.

A meeting of the Cardiff University College Association of Engineering Students of the South Wales Institute of Engineers was held at the Institution, Park Place, on Thursday evening, March 4, 1920, when a Paper was read by Mr. Richard W. Allen, C.B.E., M.Inst. C.E., of the firm of Messrs. W. H. Allen, Son & Co., Queen's Engineering Works, Bedford, on 'Mechanical Engineering.'

The President of the Students' Association, Professor Frederic Bacon, occupied the chair, being supported by Principal Trow and Mr. J. Dyer Lewis, H.M. Divisional Inspector of Mines, President of the South Wales Institute of Engineers.

The Chairman said he had received a number of telegrams and letters conveying the regret of their senders at inability to be present at the meeting. One of these was from Mr. W. H. Allen, head of the firm of Messrs. W. H. Allen & Son, wishing the Students' Association every success, and regretting that the state of his health did not permit of his making the journey to Cardiff. He (the chairman) was sure it would be in full accord with their wish that he should thank Mr. W. H. Allen for his kindly thought, and express their deep sympathy with him in respect of the cause of his absence. (Applause.) To those who attended the presentation of the Le Rhône aviation engine that afternoon to the University College it The Chairman.

The Chairman. was superfluous for him to introduce Mr. Richard Allen, who was to address them that evening. They had seen the beautiful engine he had presented to the University, and were doubtless eager to hear him read his Paper. (Applause.) To their distinguished visitors representing the parent Institution, to their fellow students from the sister Associations of East Glamorgan and Monmouthshire, as well as to the students of the Cardiff Technical College, they extended a cordial welcome. (Applause.) They had the greatest pleasure in being enabled to permit of their visitors sharing their good fortune in securing the presence of Mr. Richard Allen, who was not only a distinguished engineer but held the highest qualifications to address them on the equipment and management of a great modern engineering works. It was such men as he, who had daily to grapple with practical problems of the most important nature in conducting large engineering enterprises, that they must look for the best guidance and help in the learning and the prosecution of their profession, both from the engineering and the commercial aspect. They were deeply indebted to Mr. Allen that in the midst of his multifarious responsibilities he should have found the time and taken the trouble to come to Cardiff to speak to them. (Applause.)

Mr. Allen, who was warmly greeted, said—

# THE ORGANISATION OF A MODERN ENGINEERING WORKS, WITH SOME OBSERVATIONS UPON THE CONSTRUCTION OF SPECIAL MACHINERY, THE SCIENCE OF PRODUCTION, THE TRAINING OF PUPILS AND TRADE APPRENTICES, AND 'WELFARE.'

By Richard W. Allen, C.B.E., M.Inst.C.E.

# THE ORGANISATION OF A MODERN ENGINEERING WORKS, WITH SOME OBSERVATIONS UPON THE CONSTRUCTION OF SPECIAL MACHINERY, THE SCIENCE OF PRODUCTION, THE TRAINING OF PUPILS AND TRADE APPRENTICES, AND 'WELFARE.'

By Richard W. Allen, C.B.E., M.Inst.C.E.

I feel it a very great honour to be asked to deliver an address to the Cardiff University College Association of Students, and in selecting a subject for this purpose it occurred to me that one which would give the students of this association some thought for the future might be of advantage to them.

In this University are doubtless many students who have chosen mechanical engineering as their future calling in life, and a description of the Organisation of a Modern Engineering Works, such as those with which I am personally connected, and of the special machinery produced therein, as well as a few remarks upon the Science of Production, may be found interesting. I also propose to make some observations upon the Training of Pupils and Trade Apprentices and the Welfare of boys, so as to give some idea of the manner in which education is carried on in our works.

At the conclusion of this address I propose to show a few lantern slides illustrating some of my remarks.

## The Organisation of a Modern Engineering Works.

In dealing with the organisation of a modern engineering works one naturally recognises that the responsibility for the success of the business centres round the board of directors. They in turn depute to their various officials the responsibility for the proper management of the various branches of the establishment, which are again subdivided into departments, each under the supervision of a superintendent or foreman. I have set this out in tabular form, so that it may be easily understood how the management of the business is subdivided, and to whom the heads of the various departments are responsible for the efficient conducting of the section which they control.

Taking these departments in the order in which they come on the table, we have first the directors of the company.

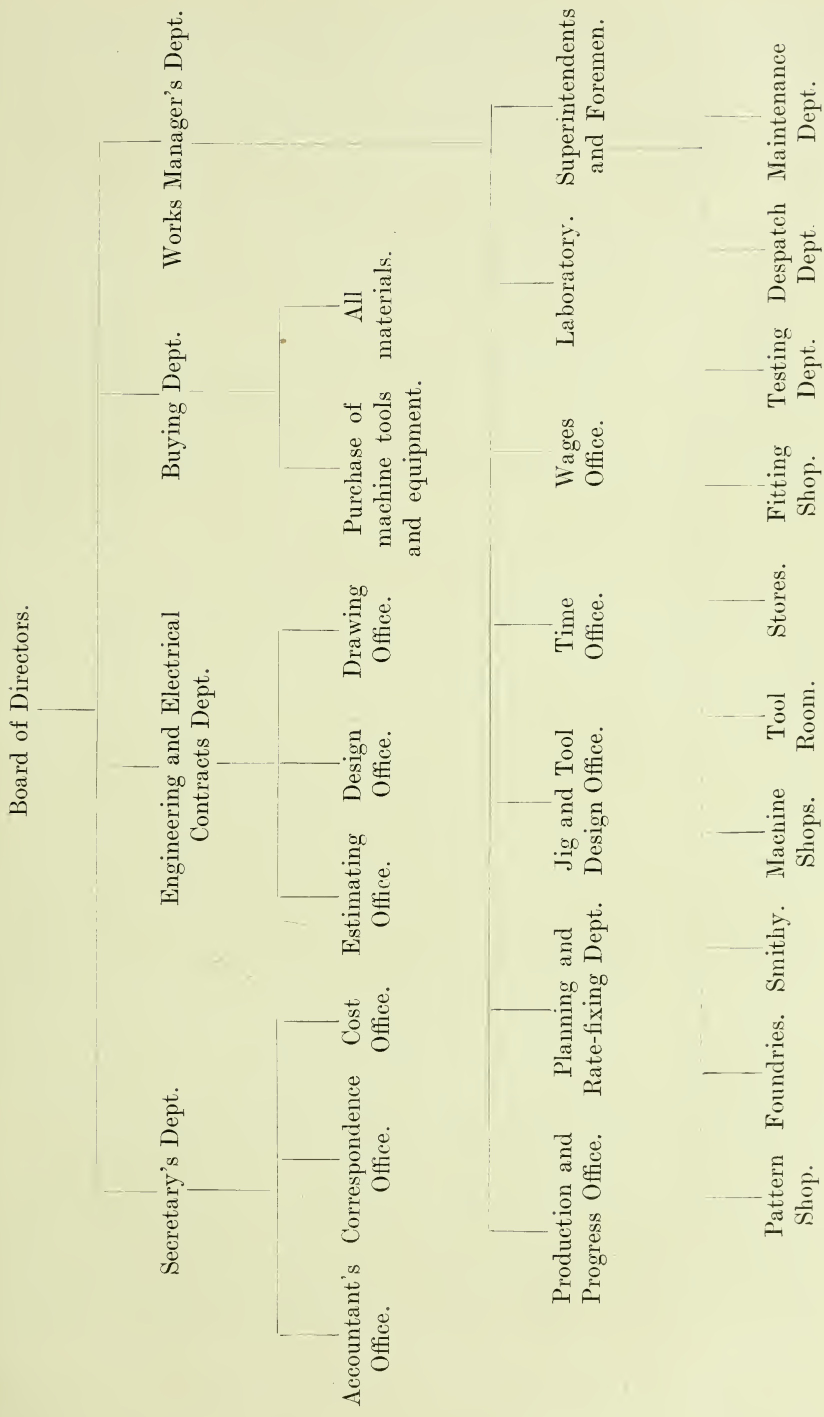
### *Directors and Management.*

The supreme responsibility for the success of the business is vested in the board of directors which forms the committee of management. The directors are engaged solely in the business of the company, and they meet daily to review and discuss the policy and financial position of the business.

The control of the works is subdivided into four principal departments: The Secretary's Department, the Engineering and Contracts Department, the Buying Department, and the Works Manager's Department.

### *Secretary's Department.*

This department is concerned with finance, the records of the company, its shares and debentures, the survey of all correspondence, recording the minutes of the directors' meetings,


Board of Directors.
Secretary's Dept.
Engineering and Electrical Contracts Dept.
Buying Dept.
Works Manager's Dept.
Accountant's Office.
Correspondence Office.
Cost Office.
Estimating Office.
Design Office.
Drawing Office.
Purchase of machine tools and equipment.
All materials.
Production and Progress Office.
Planning and Rate-fixing Dept.
Jig and Tool Design Office.
Time Office.
Wages Office.
Laboratory.
Superintendents and Foremen.
Pattern Shop.
Foundries.
Smithy.
Machine Shops.
Tool Room.
Stores.
Fitting Shop.
Testing Dept.
Despatch Dept.
Maintenance Dept.

dealing with all matters connected with the sale or purchase of property, the authorisations of expenditure, and, generally, the central control of the various operations of the business.

The departments immediately responsible to the secretary are

(*a*) The Accountant's Department,

(*b*) The Correspondence Office,

(*c*) The Cost Office.

(*a*) *Accountant's Department.*—This department keeps the record of the receipt and payment of cash, the record of sales and purchases, and is responsible for the payment of weekly wages of workmen and staff in agreement with the wages sheets. It is on the records of this office that the whole financial arrangements depend.

(*b*) *Correspondence Office.*—This department deals with the receipt and despatch of all correspondence, as well as the keeping of all records connected therewith.

(*c*) *Cost Office.*—A considerable proportion of very responsible work is performed in this office, and in the advance of modern business the cost office is likely to play a very prominent part. In the organisation of a business, its development and its ability to sell are the basis on which the whole financial structure rests. Particularly is this the case when, owing to the high price of labour and material, the continual variations in wages, and the difficulty of prices generally, the question of being able to sell at a profit, and many other matters which occur in the ordinary daily life, render it necessary that accurate records shall be kept of the cost.

The principal duties are the compilation of the records of materials used on any contract, the wages paid, and the fixing of establishment charges, which will enable them to arrive at the prime cost of any unit or group of units as may be desired.

Further, the records of fuel used, materials purchased, maintenance charges, shop expenses, working expenses, and work in progress are undertaken by this department.

One of the most difficult questions in the matter of cost to-day is the basis of establishment charges. With the high rise in the price of material and the fluctuation in wages paid, the great difficulty of fixing a percentage rate on all skilled labour costs as a basis for establishment charges is being experienced in every cost office, wherever situated. Departmental costing is one solution of the difficulty, and one which should play a prominent part in arriving at a fair distribution of the overhead charges of the several departments of a business.

### *Engineering Department.*

In this department all inquiries from intending purchasers are dealt with. The calculations are made, the size of the machinery necessary to meet the requirements of the inquiry is determined, and estimates are prepared, giving all the information regarding the plant which it is proposed to install, and the approximate date of delivery.

Should the tender result in an order being received, this order passes to the member of the engineering department who submitted the tender, who issues the necessary instructions for the design and manufacture of the machinery.

### *Buying Department.*

The buying department is responsible for the ordering of all material connected with each contract, the purchase of machinery, plant, raw material, coal, coke, iron, copper, tin, steel, timber, etc., required in connection with the business, and follows up the orders to see that they are properly executed and the delivery dates kept.

*The Works Manager.*

The works manager is responsible for the control of the works generally, and as such he is responsible for the supervision and discipline of the superintendents, foremen, and workmen, the rapid and economical carrying out of the orders in hand, and the avoidance of industrial disputes. He is entirely responsible for the dealings with labour, fixing of piecework prices, for the engagement and discharge of workmen—all of which are difficult matters at the present day. He must see that the progress of all work through the shops is expeditious, that no department has to wait for another, that the necessary planning is carried out to enable each contract to be executed economically, and that all tools, jigs, and fixtures, to simplify the various operations as far as possible, are provided. Further, he must see that the works plant is maintained in a high state of efficiency.

*Engagement of Men.*—Each applicant for employment is interviewed and a record made of his past experience. If the applicant is engaged, he is sent to the time-keeper's office, where he is given a check number, a book of rules, which is signed for, and his full name, address, age, and other particulars are made out on a ticket which accompanies him to the department to which he is allocated.

*Discharge of Men.*—Before any workman is paid off, a ticket is made out by his foreman, stating his name, check number, department, and the reason for his leaving. This ticket is then sent to the works manager's office, where it is counter-signed, and under no circumstances is the man paid off without the signature of the works manager.

The principal assistants of the works manager are as follows :

(*a*) The Works Superintendents and Foremen.

(*b*) The Production Engineer, who controls the progress of work in the shops.

(*c*) The Planner and Rate Fixer.
(*d*) The Jig and Tool Designer.
(*e*) The Head of the Works Laboratory.
(*f*) The Time-keeper.
(*g*) The Head of the Wages Department.

(*a*) *The Works Superintendents and Foremen.*—These require little description. They carry the authority of the works manager into the shops, and each one represents the works manager in his own department or shop. Much depends on their skill, energy, and tact, and the greatest care should be exercised in selecting the right men for the position. A first-class mechanic does not necessarily make the best foreman, and a bully cannot be tolerated for one moment.

(*b*) *Progress Department.*—The progress office records the progress of all work throughout the works.

Each order has a working number, by which it is referred to throughout the various departments.

Working drawings are sent from the drawing offices to this department, each drawing having a table, stating thereon clearly the material, the number off, and any other particulars of interest to the shops, for the whole of the parts shown on that particular drawing.

The progress department examines the tables of material on the various drawings for each order, and makes out a master progress sheet, showing all the parts which are required to complete the job, and this in turn is subdivided for the various departments of the works.

*Progress Meetings.*—Progress meetings, at which are present the works manager, the production engineer (as head of the progress office), the leading draughtsman, jig and tool designer, and the heads of the principal departments in the works, are held weekly, and the orders received throughout the fore-

going week are considered. At these meetings are settled the following points :—

The date the drawing will be issued to the shops,

The date the patterns will be made,

The date machining will be complete and all material delivered to the fitting shop, and

The date of the completion of the machinery and delivery to the test bay.

Once this is settled the dates should not be altered, unless very forcible circumstances necessitate it, as the whole output of the works depend upon making a programme and strictly adhering to it, otherwise no progress can be made.

*Despatch.*—When an order is completed, the machinery is sent into the testing department for testing to customers' requirements, and as soon as the tests are completed, a card recording the nature of the work, and the tests carried out, etc., is signed by the chief tester and sent to the works manager's office. At the same time the head of the despatch department applies to the secretary's office for instructions relating to despatch of the article concerned. No goods are delivered without the works manager's signature being affixed to the testing card as an indication that they are satisfactory in every way.

(*c*) *Planning and Ratefixing Department.*—This department is divided into two sections. In the first section the various components of any job are carefully considered, and the necessary series of operations to transform the rough casting or forging into the finished part are planned out. In the other section the piecework rates for the various operations are settled, also any bonuses under the various systems of payment by results in vogue in the works.

(*d*) *Jig and Tool Design Office.*—This department works in close conjunction with the planning department. When the operations on any casting or forging have been planned out,

the operation sheet and the drawings are passed on to the jig and tool designer, who decides what jigs and tools are necessary to carry out the work quickly and economically. This department makes the drawings for all the jigs and tools required, and passes them on to the tool room for construction.

(*e*) *The Works Laboratory* is responsible for the testing of all material used in connection with the various contracts. It investigates all such questions as the heat treatment of steels, behaviour of various metals under the conditions of working, fatigue in working parts, and many others. A well-equipped, well-conducted laboratory is of inestimable benefit to any large works.

(*f*) *The Time Office.*—This office is responsible for recording the arrival and departure of all employees, whether workmen or staff. The record of workmen's time is, of course, more important, as they are paid on the basis of time, whereas the staff is usually paid on the basis of a weekly or monthly salary.

(*g*) *Wages Department.*—Owing to the different rates of wages payable to the various grades of labour in any large works, to which must be added awards granted by the Government, and increases arranged at conferences between employers and employed, also bonuses under systems of payment by result, and bonuses payable to certain men, such as charge hands,—the work of a wages department is a complicated and onerous one. There are also the deductions for National Health and Unemployment Insurance to be made, and the weekly contributions to such funds as works benevolent fund, etc.

Speaking generally, the wages are based either on time or piece work or some method of payment by results. The various rates payable to the different classes of workmen are notified to the wages office by the works manager's office, and any alterations made from time to time are notified accordingly.

*Stores.*—This is another very important branch of any business. It is frequently the case, whilst a very stringent record is kept regarding finance, that stores, the value of which is often much greater than any amount of cash on hand at any one time, are frequently not looked upon in the same light; and shortages, which often occur in many departments, are treated somewhat lightly. Correct storekeeping is one of the most essential features in a well-conducted business, and it is necessary that the strictest and closest records be kept of all transactions in and out, and also the currency of stores in the custody of the storekeeper. It may be pointed out that the storekeeper's records are in quantities and not in money value.

### *Works Committees.*

I am strongly in favour of works committees, and the experience gained from the working of these—especially during the war—was of the greatest value and assistance in maintaining happy relations between the management and the men. The employees appoint their own works committee, one or two from each department being appointed, and from the general works committee special committees are formed to deal with such matters as dilution, working conditions, and others that arise from time to time. The meetings are held generally once a month, unless some urgent matter is raised on either side, which necessitates a special meeting. The management is represented by seven members, with the works manager in the chair, and one of the foremen as secretary. An agenda is made out prior to each meeting and handed to the secretary of the works committee, who on their part may hand an agenda of any points they wish to raise to the secretary of the management committee. Many points which might grow and cause friction can be settled in the early stages. Provided the works committee has the confidence of both the management

and the workpeople, the results cannot be anything but beneficial to all concerned.

One point I cannot emphasise too strongly is that it is most desirable, if not essential, that any complaint raised by the workmen should first be dealt with by the foreman of the department in which the complaint is made, and failing a satisfactory solution, the matter should be brought to the notice of the works manager without any delay. Delays and apathy in this direction are the source of many disputes which, if dealt with promptly and firmly, would never arise.

## Construction of Special Machinery.

For success in this class of work it is essential that works should be designed and constructed on the most modern principles, and, furthermore, that it should be equipped throughout with machine tools of the latest type and with the most effective labour-saving devices.

I propose now to give a short account of some of the machinery being constructed in the works, which may be grouped under the following headings :—

(*a*) High speed engines,
(*b*) Dynamos,
(*c*) Condensing plant,
(*d*) Centrifugal pumps,
(*e*) Steam turbines,
(*f*) Oil engines.

(*a*) *High Speed Engines.*—There is here little need for description. The High Speed Engine, which is so well known, is made in sizes from 25 to 2500 H.P., is very simple in design, is of substantial proportions, and has large bearing surfaces suited for continuous running, so that it can operate for long periods with little attention.

Close consideration has been given to the question of choice and suitability of materials.

A centrifugal governor is fitted, while hand-regulating gear permits considerable range of speed.

(*b*) *Dynamos.*—These are of the D.C. compound-wound type, with steady voltage at all loads. Again, full consideration has been given as regards dimensions and materials and to ensure effective cooling and insulation.

The winding is of the drum-barrel type, consisting of well-insulated interchangeable high conductivity copper bars or coils independently formed, while the magnet yoke is usually in halves to facilitate vertical withdrawal of the armature. Where necessary, commutator poles are fitted.

(*c*) *Surface Condensing Plants.*—Considerable advance in the construction of surface condensers has been made during the last few years.

The condenser itself is usually circular in form, is supplied with branches for the main exhaust, water extraction, and circulating water inlet and outlet piping, and is tested hydraulically both inside and outside the tube plates to a pressure of 30 lb. per sq. inch. Multiple flow condensers are more efficient than the single-flow type.

Various methods of evacuation are in vogue.

(1) Reciprocating air pumps of the vertical Edwards type may be used. The condenser water after leaving the air pumps should run away by gravity. In the event of the air pumps having to deliver against a head, a suitable force pump must be provided, driven by means of a connecting rod from a disc crank keyed on one end of the air pump crankshaft.

(2) A second method is the kinetic rotary type, embodying steam and water ejectors. The air and non-condensible gases are removed from the air outlet of the condenser by being entrained by a high velocity steam jet.

As an alternative form of the last, a 'Kinetic Steam Jet Air Pump' is sometimes supplied, which consists of primary and secondary steam ejectors working in conjunction with an intermediate condensing receiver, the supply of cooling water for the latter being furnished from the condensate pump. The steam, together with the air from the ejectors, is discharged into a tank into which the condensate extraction pump also delivers.

Both the circulating pumps, which are usually of the centrifugal type, and the reciprocating air pumps can be driven either by a steam engine or electric motor, the two pumps being driven separately or together, as may be most suitable. The Edwards air pump is usually driven through metal to metal gearing, with machine-cut teeth running in an oil-tight gear case.

(*d*) *Centrifugal Pumping Machinery.*—These are used for main circulating purposes both on H.M. ships and in those of the Mercantile Marine, for the pumping out of large graving docks (as at Cardiff, Penarth, Barry, Swansea, Liverpool, Birkenhead, Wallasey, and many other places), for fen drainage, waterworks, irrigation and similar purposes.

They may be steam or electrically driven.

(*e*) *Steam Turbines.*—For small units the impulse type, when either radial or axial flow is employed, is much in favour, chiefly for its efficiency at low speeds; and therefore it is particularly adapted for coupling to alternators, pumps, and fans, for which purposes both the Admiralty and Mercantile Marine have lately adopted it to a great extent.

For larger units the Parsons Impulse Reaction type is usually adopted, which requires to be suitably governed, and for ship work needs special care being given to the lubrication system to provide for the conditions obtained when the vessel lists. A notable feature of this is that the gear wheel is so arranged that it is always clear of the oil in the reservoir.

On account of the fact that turbines are most efficient at a high speed, while for pumps, dynamos, or fans a low speed gives much the best results, there is a strong trend nowadays towards the introduction of geared turbines.

(*f*) *Heavy Oil Engines.*—There is an increasing demand for these engines for both land and marine work.

In this instance the two-stroke cycle is employed, one, two or four cylinders being used, according to the power required. The same working parts are used as far as possible for all sizes to facilitate production. Interchangeability is ensured by the use of special jigs and fixtures and by limit gauges.

The principle of surface ignition is employed, the fuel being injected immediately before ignition occurs. A blow-lamp is used for a few minutes in starting, after which the engine will run indefinitely at any load without the lamp being again required or any additional device being used for ignition.

The chief advantages of this engine are the absence of valves, its ability to run satisfactorily on practically any kind of residue oil, the fact that it can be operated satisfactorily by native labour, and its low fuel consumption, 0·5 pints of oil per B.H.B. hour.

No water-drip is employed, this having been found to lead to corrosion, primarily due to the sulphur compounds in the oil, while also it needs continual adjustment under varying loads.

These engines are being constructed in standard sizes from 25 B.H.P. to 230 B.H.P.

## Science of Production.

In dealing with this question one recognises that in all our great universities the Science of Engineering is taught,

but, so far as I know, the question of the Science of Production has not hitherto been considered.

This important subject was brought before the public in a far-reaching way by Dr. Edward Hopkinson in his presidential address to the Institution of Mechanical Engineers in 1919.

We all realise that we shall never regain our former great position in the world unless production in our country is very much increased, and for this reason I consider that this subject could be very advantageously dealt with in all our universities.

Many vital questions engage the attention of the mechanical engineer of the present day, and must be dealt with successfully if we are to ensure the maintenance of our national position in the engineering world.

There is often room for much improvement in our methods of manufacture, for, from the point of view of competitive efficiency, it should scarcely be necessary to state that the method of manufacture of a product is as important as the design itself.

Success in this direction can naturally only be obtained by means of a low cost of manufacture, which is again dependent upon a high rate of production, and the attainment of this desirable state is only possible with a highly efficient organisation of the workshops.

There is no progress except in change, and at no period in the past have our engineering methods been of such a transitive character as at the present moment. It is therefore the man with the young and flexible mind, with administrative and organising capacity, who is needed in industry. We live in an age of new discoveries and new ideas, and for that reason the men trained in the University and the Technical School are best fitted to grapple with the daily fluctuating problems of the modern engineering workshop. The requisite

capacity of these men should be partly natural, but also largely acquired and developed by training. The training should be specifically such as should fit them for the administrative posts. That is to say, the teaching of administration and organisation, both of which are based upon definite scientific principles capable of being readily taught, should be a recognised portion of the curriculum of engineering education, even if less time has therefore to be allocated to mechanics, the basis of the engineer's profession.

There is naturally no general system of production which can be applied to all works. At the same time the basic principles of economic production are always the same, and there is no doubt that these principles can be more readily expounded in the University and the Technical School than in the factory. The young men who have spent all their time in the workshop, and have therefore not exercised their minds beyond the demands of their daily occupation, are less fitted for the administrative positions than those with the proper theoretical training and the natural practical bent who have been schooled to think as well as to act. It is also possible for the student in the technical schools to specialise, so that later in the workshops he may be able more quickly to absorb shop experience in his own subjects and so perfect himself for those specialised administrative positions we have in view.

It must steadily be borne in mind that the University training must be of such a nature as has been previously indicated, and that a much larger proportion of the time should be devoted to the teaching of the principles of production, the right use of tools and the accommodation of design to suit methods of production. It is possible to foster interest in the subject by encouraging the reading and circulation of papers upon workshop organisation and production from machine tools.

While it is thus necessary to review our methods of training

men for the administrative staff, it is no less necessary to consider the education of the manual workers themselves. No management, however scientific, can be successful unless due regard is given to the human element. To ensure success it is necessary that every worker should feel—no matter how humble his work may be—that he is a necessary member of the team.

It is obvious that high efficiency in production benefits the worker just as much as the employer. It is therefore of the first importance that the workers should fully appreciate the interdependence of successful workshop organisation. It is probable that a good deal of the unrest that is to be found in the present day in engineering workshops is due to the lack of education of the workers, and this is at any rate partly due to the lack of foresight shown by engineers in the past. It is *not merely* necessary to train men in the most efficient manner to be mechanics, but also to be citizens.

Efforts are now being made to demonstrate to every workman the ultimate object of his own particular labour, so as to give him a keener interest in it. He should also be taught the principles on which all systems of payment are based. All changes, and the reasons for the same should be fully explained to him. Attention should be given to the physical health and mental contentment of workers, as upon these depend largely their efficiency of production. The subject of industrial fatigue should be studied exhaustively, so as to relate the number of hours worked to the output obtained. The various motions requiring to be performed by each man in doing his particular work must be studied, so that his muscular effort is not being wasted in superfluous movements. At the same time he must understand clearly that this is all for his own benefit, and may often result in his doing less work but producing a greater output.

In any well-organised works, provision must be made for the adequate training of the future engineers and mechanics, not exclusively for materialistic ends, in that a greater intellectual power results in increased production, but also to promote the mental development of the individual, and so to enable a higher conception and a fuller attainment of happiness in life to be obtained.

To enable this ideal to be achieved, it is necessary that each individual should be directed to that profession or trade for which he is best adapted, and in which his ability will best find expressions. In the past, the responsible educational authorities have frequently not realised fully the necessity for this but the matter is now being far more thoroughly dealt with.

The part which is taken in training the future engineers and mechanics in our works may now briefly be considered.

## Training of Pupils and Trade Apprentices.

*Entry.*—Pupils usually come into the works from the public schools at about seventeen years of age and remain for four years.

The educational attainments required of candidates for pupilage approximate to University Matriculation standard, and if a prospective pupil has not passed such an examination he is tested in English, Mathematics, and Science before entering upon his pupilage. A limited number of pupils come into the works after their college training and complete a three years post-graduate pupilage.

*Works Training.*—The training of pupils is supervised by the Pupils' Demonstrator, who is also the head of the educational department of the company.

An engineering pupil will usually first of all spend a few

months in the foundries, the pattern shop, and, in some cases, the smiths' shop. The machine shop will then occupy his attention for the next six or eight months. Here he is instructed in all branches of machine work and milling, commencing with the smaller machines, such as centre lathes, and as he gains in confidence and ability he is transferred to the larger machines in the light and heavy turnery and the milling bays.

He is then transferred to the fitting shop, passing rapidly from bench to bench in order to gain experience in the fitting of centrifugal pumps, steam turbines, high speed steam engines, and crude oil engines. At this point a short period in the electrical department is generally arranged, where the pupil obtains a general acquaintance with the construction of electrical machinery, after which he may also spend a few months in the electrical test bay, where the dynamos and electrical gear are tested prior to being despatched from the works.

The final stage in his works training is reached in the steam test bay, where the testing of engines, turbines, pumps and other steam plant is conducted under the severest working conditions by means of instruments of the highest accuracy.

*Office Training and Outdoor Work.*—At various times during the latter part of his workshop training, opportunities may arise for him to assist in the installation of the company's machinery either at home or abroad, and at the expiration of about two and a half years he should have obtained a fairly wide practical training. He would then spend about a year in the drawing office, and complete his pupilage by becoming attached to the administrative or commercial side of the business, by which means he would become acquainted not only with the design and construction of engineering machinery, but also

with the factory and office organisation necessary for its construction and distribution.

*Education.*—During the whole of this time the pupil is not only instructed in the various details of construction, but is also supervised by the Pupils' Demonstrator, who plans his course through the works and sees that the pupil is getting the full benefit of the training. Throughout their pupilage the pupils are withdrawn from the shops for six hours per week to attend lectures, for which a well-equipped lecture room is provided. Lectures are given on various subjects connected with engineering, including Mathematics, Applied Mechanics, Heat Engines, Magnetism and Electricity, Metallurgy, Properties of Materials; and there is also a course in Machine Drawing and Design. Most of these lectures are delivered by the Demonstrator, but in special cases other officials of the works give courses of lectures on subjects on which they are specially qualified.

The lantern and various models are used freely for the illustration of these lectures, and where it is thought advisable special demonstrations of tests, etc., are given in the Works Research Laboratory.

*Prizes and Scholarships.*—Prizes are awarded each year to the pupils who show marked ability and perseverance in the workshops and lecture room.

A University Scholarship is offered annually of the value of £100 per annum for two or three years, tenable at the Imperial College of Science and Technology, or some other College of the University of London, to the best pre-graduate pupil in each year.

In awarding this scholarship, consideration is given to the workshop and timekeeping records, the results of examinations held at the termination of lecture courses, the Demonstrator's reports, and any other evidence of special

fitness which appears to justify the award. No undertaking is given to award the scholarship except to candidates whom it is deemed possess sufficient merit.

Candidates must have served as a pupil in the works for at least three years.

Successful candidates are required to enter the College in the autumn term, and to pursue a course of study approved by the Principal of the College. A continuance of the scholarship depends upon the good conduct and progress of the holder.

The scholarship money is paid to successful candidates in equal instalments at the beginning of each College term.

### *Trade Apprentices.*

*Entry and Workshop Training.*—Trade apprentices usually enter the works as prospective apprentices at about fifteen years of age. At sixteen years of age they are indentured to a particular trade, such as fitting, turning, pattern-making, dynamo making, etc. They learn their trade in the various shops under the direction of the foremen, and the Demonstrator also watches over their workshop training.

*Education.*—These apprentices are drawn from the works to attend classes during eight hours in each week until they attain the age of eighteen years. Apprentices above eighteen years of age attend classes if they have shown themselves to have sufficient ability and application. These classes include instruction in the following subjects :—English, Citizenship, Mathematics, Science, Drawing, Physical Instruction, and for the senior apprentices instruction in trade subjects.

*Opportunities for Advancement.*—Trade apprentices who show themselves to have considerable aptitude are drafted from the shops into the drawing offices to have training as draughtsmen, and there is also a scholarship system by which trade apprentices may be transferred to pupils.

## Welfare.

What is Welfare ? We may define this, I think, as the systematic attempt to humanise industry. It consists of voluntary efforts on the part of employers to improve within the existing industrial system the conditions of employment in their own works. To have a permanently efficient worker you must have a good citizen, developed both in mind and body, with a healthy outlook on the world, with keen ambition and true conception of his responsibilities to his fellow workers, to the firm for which he works, and to the community. Whatever tends to develop these qualities is in the true sense welfare work.

As proof of the importance attached by employers to welfare work I might here mention the Industrial Welfare Society. This is a society of which all the leading firms of the country are members, and it exists for the purpose of focussing and developing the many activities—industrial, educational, and recreational—indicated by the word ' welfare.'

The society was formed originally for the purpose of dealing with industrial boys, but recently its scope has been enlarged in order to embrace all industrial workers.

The object of the society is to retain for industry itself the responsibility for, and the direction of, industrial welfare work.

A great honour was conferred on the society when H.R.H. Prince Albert accepted the position of president. By this personal interest, and by his visits to works where welfare schemes are in progress, he has impressed upon the public the importance and usefulness of the movement.

It is with boy welfare that I would especially deal here. Those familiar with boy labour, and the conditions under which it was employed before the war began, realise the great waste

and neglect which dominated the whole system at that time employed. The boy's education was cut short, since he left school, as a rule, at a very early age, and immediately became a wage-earner. Owing to lack of advice, and very often the lack of means at home, he entered a 'blind alley' occupation. As years went on he gradually drifted, and was thus unprepared for any serious industrial employment.

When this state of affairs had continued for a considerable period, a general feeling arose that it was necessary to take in hand the reclamation of the boy from the dangers in which he was fast becoming involved, and that it was desirable, as a means to this end, effectually to control and care for the boy in some manner so that he might be in the best condition morally, mentally, and physically for future industrial needs.

Boy welfare may be roughly divided into two sections—that connected with work which includes engagement, dismissal, progress, discipline, training, etc., and that concerned with recreation, although, in practice, the two sections are very closely associated.

Upon engagement the Welfare Supervisor records in the case of each boy such particulars as parentage, school, sports and hobbies, etc., and these data are filed by the card index system. The opportunity is also taken of having a chat with the boy about his future work and prospects. His height, weight, and chest measurements are taken, and a permanent record made. The importance of a periodical record of these physical measurements and weights cannot be too strongly emphasised, for thereby can be noted the effect on his physique of the class of work in which the boy is engaged, and an early indication can be obtained of any falling-off in health due to unsuitability of occupation or from other causes.

In the event of the boy being medically examined, the disability from which he may be suffering is brought to the

notice of the Supervisor, so that he may take any necessary steps to expedite recovery.

In any case, close touch is kept with every boy after he has commenced work. He is visited while he is at work, and he in turn may visit the Supervisor at the Welfare office at fixed hours. To prevent frivolous complaints the hours are fixed in the boy's own time. Home visits have been commenced in cases of sickness or accident. It has also been found that in some cases of dismissal or suspension a visit to the parents does much to ease any unpleasant feeling which might exist.

With regard to recreation, every endeavour should be made to inaugurate games, such as cricket, Association and Rugby football, hockey, lawn tennis, bowls, etc.

A development introduced in many works is the provision of a Boys' Club. The whole idea of a Boys' Club rests on the fact that the working boy is never content unless he is a member of some party or crowd. There is no doubt whatever that one of the best ways to help boys is by the provision of a club, as it is a useful instrument for teaching the boy or youth the meaning of a corporate life and individual responsibility. The club should comprise games rooms—one for seniors and one for juniors—with tables and games of all kinds, including cards, draughts, chess, dominoes, etc., and perhaps a billiard room, with comfortably furnished reading and writing rooms, and a stock of the latest magazines and papers; other developments may be made as occasion requires, such as a musical society or debating club.

All boys in a works between the ages of fourteen and nineteen should be eligible for membership. The Executive Committee should be entirely composed of boys who have been drawn from the different classes of boys in the works—pupils, trade apprentices and non-apprentices; the Welfare Supervisor acting as chairman of the Executive Committee.

A gymnasium might also form a very important part of any club. The necessity for some degree of physical education of the young is now happily far more generally recognised than was the case a few years ago.

For the welfare of all the employees generally, both men and women, the following forms a very important part in the works :

(*a*) The Works Surgery, where all injuries are promptly attended to by a nurse.

(*b*) The Canteen, where employees can either obtain meals comfortably or have their own food cooked or heated.

(*c*) Men's Institute.

(*d*) Recreation Club.

All these have the tendency to improve the conditions of the working classes to-day.

In conclusion, I earnestly wish every success to all the students of the Cardiff University, and I trust that the remarks which I have made on the important subjects touched upon may prove to be of some help and interest to you all.

After exhibiting and explaining the features of a large number of photographs cast on the lantern screen,

Mr. ALLEN, reverting to the question of Welfare, said Prince Albert was a member of the Council of the Welfare Association. He had seen a great deal of His Royal Highness during the past twelve months, and his interest in the work of the Association was of the most earnest character. Indeed, their Majesties the King and Queen, and every member of the Royal Family, had shown, and continued to show, a wonderful example in doing real, practical good for the country and the Empire. (Applause.) Each member of the Royal Family was engaged in furthering some beneficent cause or other. Mr. Lloyd George had said, a few days ago, what a great asset H.R.H. the Prince of Wales was to the Empire. (Applause.) **Mr. Allen.**

Mr. Allen. After his visits to Canada and Australia he would have acquired a close knowledge of His Majesty's splendid Dominions that would go far indeed to cement the bonds of Empire in perpetuity. King George was very wise in the way he was bringing up his children. Prince Albert had chosen, with much wisdom, to take up Welfare as his particular work, and at every opportunity that presented itself, apart from his studies at Cambridge University, he visited some place or other to see for himself the conditions in which the young people of this country were employed in the various large industries upon which the future of the nation so much depended. In this way he was able to draw comparisons, and even to give suggestions to employers based upon what he had seen in the course of his visits. When His Royal Highness visited the Bedford Engineering Works he was greeted by some 390 boys, who gave him a rousing welcome. To show the trouble the Prince was willing to go to in order to get to the bottom of things, His Royal Highness on this occasion spoke individually to no fewer than 110 of the lads—(applause)—and was pleased to express his pleasure at what he had seen at the works from the Welfare side. Naturally, the firm were gratified that their efforts in this direction met with appreciation in such a quarter. (Hear, hear.)

The Chairman. The CHAIRMAN said he would venture to assert that the present occasion would long remain a Red Letter Day in the annals of the Association. (Applause.) Next to their gratitude to Mr. Allen—and they must all feel deeply grateful to that gentleman—they had to acknowledge with cordial appreciation the kindness of the parent Institution, the South Wales Institute of Engineers, in enabling them to put an appropriate setting to the lecture by having it delivered in that handsome hall. They were delighted to see with them Mr. Dyer Lewis, the President of the Institute—(applause)

—who would be doubtless pleased to have the 'Proceedings' enriched by Mr. Allen's most useful contribution. (Applause.)

The PRESIDENT OF THE INSTITUTE said seldom had he listened to a more informative address than that which they had just had from Mr. Allen. By the aid of very fine lantern slides, they had obtained an idea of the splendid works at Bedford which would long remain with them, and to many of the students these works must indeed be a revelation. It was evident that in the construction of the beautiful machines that had just been illustrated the workmen took a pride and pleasure in their duties, which they were able to discharge in as nearly ideal conditions as it was possible to conceive. He trusted that the publication of Mr. Allen's paper in the Institute's 'Proceedings' would lead to the creation, in the not distant future, of similarly designed and equipped works in South Wales. **The President.**

Mr. ROBERTS, Hon. Secretary of the Association, proposed a vote of thanks to Mr. Allen. He said he was expressing the thought of every fellow-student when he said they warmly appreciated the opportunity of culling knowledge from so unimpeachable a source as Mr. Allen. When he met that gentleman earlier in the day he got the impression that his employees must have a jolly good time, but since hearing the Paper and seeing the photographs he had come to the conclusion that the works must be a veritable paradise. (Laughter and applause.) With reference to the Le Rhône engine that Messrs. Allen had presented to the University College, he could not understand why manufacturers had failed to cultivate this fertile ground, because, after all, they were embryo engineers. If they had faith in the plant they manufactured, it would be worth while for them to send specimens to the College. They would, at any rate, be certain of having them criticised. (Laughter.) **Mr. Roberts.**

Mr. Smith.

Mr. SMITH (student) seconded the resolution of thanks to Mr. Allen. With regard to the Le Rhône engine, his only regret was they had not yet a suitable place for it at the engineering department of the College.

Acknowledging the vote of thanks, which was carried by acclamation,

Mr. Richard Allen.

Mr. RICHARD ALLEN said it had afforded him sincere pleasure to come amongst the students. He had been looking forward to his visit with keen interest. He had long felt that when engineers found they could do something to encourage and help on the budding engineer, it was their duty to avail themselves of the opportunity, because upon the students of to-day would rest the responsibility in the future of carrying on and developing the great industrial works of the Empire. He should retain pleasant memories of his latest visit to Cardiff and to the University College Engineering Students, whom he wished full measure of success in their studies and their post-college careers; and if at any time he could help any of them along in the world, let them write to him and he would do his best for them. (Applause.)

The proceedings then terminated.

# PROCEEDINGS.

## Sixty-Second Annual General Meeting.

The Sixty-Second Annual General Meeting of the Institute was held at the Institution, Cardiff, on Friday, March 26, 1920.

The chair was occupied by Mr. J. Dyer Lewis, the President.

The Secretary read the Minutes of the Preceding General Meeting, held on February 19, 1920, and they were confirmed.

## Candidates for Admission.

The following candidates for admission to the Institute were declared duly elected :—

*As Members.*

| | |
|---|---|
| Earle, John Waterman . | Bridgend. |
| Jones, Reginald Gwyn . . | Neath Abbey. |

*As Associates.*

| | |
|---|---|
| Cook, George . . . | Deri, near Cardiff. |
| Davies, David . . . | Mardy, Rhondda. |
| Jones, Benjamin Lloyd . . | Mardy, Rhondda. |
| Morgan, Edwin John . . | Pantygraigwen, Pontypridd. |
| Morris, Russell John . . | Mountain Ash. |

## Admission of New Members.

The following gentlemen, having been previously elected, signed the Roll Book, and were admitted to the Institute :—

*As Members.*

| | |
|---|---|
| Jones, Edward Cyril . . | Pontypridd. |
| Roberts, Sidney Douglas . | Cardiff. |
| Thomas, Sydney . . . | Cardiff. |
| Williams, Edward Samuel . | Abertridwr. |
| Wolff, Salomon . . . | Cardiff. |

*As Student.*

| | |
|---|---|
| Howells, Jenkin Owen . . | Gwauncaegurwen. |

## Financial Statement.

The Financial Statement of Accounts for the session ended December 31, 1919, duly audited, was submitted, printed copies having previously been distributed among members, as on pages 121, 122.

**Mr. Edward Dawson.** Mr. Edward Dawson, chairman of the Finance Committee, proposed the adoption of the Financial Statement.

**Mr. W. Forster Brown.** Mr. W. Forster Brown seconded, and the motion was agreed to.

**Mr. Dawson. Mr. F. Ll. Jacob. Mr. Hugh Bramwell.** Messrs. Macdonald and Rees were re-elected auditors, on the proposition of Mr. Dawson, seconded by Mr. F. Llewellin Jacob ; and Lloyds Bank was reappointed treasurer, on the motion of Mr. Hugh Bramwell, seconded by Mr. Dawson.

## Election of Secretary.

**The President.** The President proposed the re-election of Mr. Martin Price as Secretary of the Institute. He said Mr. Price had now served the Institute for many years, and they would all

## FINANCIAL STATEMENT—SESSION ENDED DECEMBER 31, 1919.

| Receipts. | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| To Balances, December 31, 1918:— | | | | | | |
| Lloyds Bank, Current Account | 76 | 1 | 9 | | | |
| ,, ,, on Deposit, Building Redemption Fund | 69 | 13 | 0 | | | |
| ,, ,, Library Equipment Fund | 14 | 10 | 3 | | | |
| ,, ,, General Deposit Account | 103 | 18 | 6 | | | |
| Petty Cash in Hand | 4 | 4 | 9 | | | |
| | | | | 268 | 8 | 3 |
| ,, Members' Subscriptions:— | | | | | | |
| Current Session, 1919 | 1,362 | 18 | 0 | | | |
| Arrears | 48 | 8 | 0 | | | |
| In advance for 1920 | 45 | 3 | 3 | | | |
| | | | | 1,456 | 9 | 3 |
| ,, Sale of Institute 'Proceedings' | | | | 75 | 11 | 8 |
| ,, Sale of 'Lectures on Mining' | | | | 2 | 8 | 0 |
| ,, Sale of Paper, 'The South Wales Coalfield' | | | | 5 | 5 | 0 |
| ,, Advertisements | | | | 175 | 18 | 6 |
| ,, Institute Buildings:— | | | | | | |
| ,, Monmouthshire and South Wales Coal Owners' Association—Proportion of Maintenance Charges | | | | 722 | 15 | 6 |
| ,, Fees | | | | 31 | 3 | 6 |
| ,, Sale of Sections | | | | 3 | 16 | 0 |
| ,, Lewis Prize Fund—Interest | | | | 14 | 14 | 1 |
| ,, Building Redemption Fund—Interest | | | | 34 | 7 | 1 |
| ,, Library Equipment Fund—Interest | | | | 2 | 17 | 3 |
| ,, General Investments Fund—Interest | | | | 138 | 7 | 9 |
| ,, Spence Thomas Scholarship—Interest | | | | 48 | 16 | 11 |
| | | | | £2,980 | 18 | [illegible] |

| Payments. | £ | s. | d. | £ | s. | d. |
|---|---|---|---|---|---|---|
| By Cost of Proceedings, Printing and Stationery | | | | 404 | 13 | 0 |
| ,, Reporting | | | | 40 | 10 | 4 |
| ,, Secretary's Salary | | | | 400 | 0 | 0 |
| ,, Postages and Telegrams | | | | 45 | 9 | 9 |
| ,, Swansea Room, Rent, etc. | | | | 39 | 1 | 8 |
| ,, Wages of Office Staff | | | | 80 | 0 | 0 |
| ,, Students' Association, Payments on Account | | | | 30 | 0 | 0 |
| ,, Lanternist | | | | 3 | 3 | 0 |
| ,, Bank Charges | | | | 3 | 0 | 9 |
| ,, Legal Expenses | | | | 4 | 2 | 9 |
| ,, Incidentals | | | | 2 | 8 | 0 |
| ,, Returned Fees | | | | 4 | 4 | 0 |
| ,, Scholarship and Exhibitions:— | | | | | | |
| E. W. H. Knight, Honorarium | 10 | 0 | 0 | | | |
| Myrddin David, Inst. Scholarship on Account | 25 | 0 | 0 | | | |
| J. S. Caswell, Inst. Exhibition on Account | 15 | 0 | 0 | | | |
| E. Gordon Davies, Inst. Exhibition | 28 | 0 | 0 | | | |
| | | | | 78 | 0 | 0 |
| ,, Spence Thomas Scholarship: | | | | | | |
| W. J. Gilbert, on Account | | | | 25 | 0 | 0 |
| ,, Lewis Prizes, 1918:— | | | | | | |
| W. T. Lane, 1st Prize | 25 | 0 | 0 | | | |
| W. H. Casmey, 2nd Prize | 5 | 0 | 0 | | | |
| | | | | 30 | 0 | 0 |
| ,, Purchase of £850, 4% Funded Loan (1960–1990) | | | | 680 | 0 | 0 |
| ,, Sale of Papers: "The South Wales Coal Field" | | | | 9 | 9 | 0 |
| ,, Institute Buildings:— | | | | | | |
| Ground Rent, less tax | 35 | 0 | 0 | | | |
| Insurance | 24 | 13 | 7 | | | |
| Rates and Taxes | 151 | 4 | 7 | | | |
| Lighting and Warming | 250 | 18 | 8 | | | |
| Repairs | 61 | 5 | 8 | | | |
| Painting Premises | 235 | 8 | 0 | | | |
| Caretaker's Wages, etc. | 123 | 10 | 0 | | | |
| Extra Cleaning | 28 | 1 | 6 | | | |
| Sundry Stores | 37 | 15 | 0 | | | |
| | | | | 947 | 17 | 0 |
| ,, Balances, December 31, 1919:— | | | | | | |
| Lloyds Bank, Current Account | 16 | 15 | 2 | | | |
| Do. Deposit, Building Redemption Fund | 24 | 0 | 1 | | | |
| Do. Do. Library Equipment Fund | 17 | 7 | 6 | | | |
| Do. General Deposit Account | 95 | 8 | 9 | | | |
| Petty Cash in hand | 0 | 8 | 0 | | | |
| | | | | 153 | 19 | 6 |
| | | | | £2,980 | 18 | [illegible] |

# BALANCE SHEET—DECEMBER 31, 1919.

| ABILITIES. | £ | s. | d. |
|---|---|---|---|
| Sundry Creditors | 6 | 16 | 6 |
| Lewis Prize Fund | 551 | 10 | 2 |
| Members' Subscriptions paid in advance | 45 | 3 | 3 |
| Building Redemption Fund, per Contra | 842 | 17 | 4 |
| Library Equipment Fund, per Contra | 67 | 7 | 6 |
| Institute Deposit Account | 316 | 13 | 2 |
| Spence Thomas Scholarship Fund | 1,063 | 10 | 0 |
| Capital Account, Balance, being excess of Assets over Liabilities | 17,997 | 6 | 0 |
| | £20,891 | 3 | 11 |

| Assets. | £ s. d. | £ s. d. | £ s. d. |
|---|---|---|---|
| Cash at Lloyds Bank, Current Account | | 16 15 2 | |
| Do. Do. General Deposit Account | | 95 8 9 | |
| Petty Cash in Hand | | 0 8 0 | |
| | | | 112 11 11 |
| Members' Subscriptions in Arrears | | | 213 6 11 |
| Sundry Debtors | | | 310 8 1 |
| Stock of Proceedings, Nominal Value | | | 20 0 0 |
| Stock of Lectures on Mining, Do. | | | 10 0 0 |
| INVESTED FUNDS :— | | | |
| £2,000 Cardiff Railway Co. 3% Deb. Stock at Cost | | 2,141 19 0 | |
| £1,400 War Stock, 1929–47, 5% Deb. Stock at Cost | | 1,321 16 1 | |
| £750 Funded Loan, 1960–90, 4% Deb. Stock at Cost | | 600 0 0 | |
| | | 4,063 15 1 | |
| LEWIS PRIZE FUND :— | | | |
| £243 Barry Railway Co. 3% Deb. Stock at Cost; £253 Cardiff Railway Co. 3% Deb. Stock at Cost | | 500 0 0 | |
| BUILDING REDEMPTION FUND :— | | | |
| £150 Cardiff Railway Co. 3 Per Cent. Debenture Stock at Cost | £119 15 0 | | |
| £390 Rhymney Railway Co. 4 Per Cent. Preference Stock at Cost | 379 2 3 | | |
| £250 War Stock 1929–47, 5 Per Cent. Preference Stock at Cost | 240 0 0 | | |
| £100 Funded Loan, 1960–90, 4 Per Cent. Preference Stock at Cost | 80 0 0 | | |
| Cash on Deposit at Lloyds Bank | 24 0 1 | | |
| | | 842 17 4 | |
| LIBRARY EQUIPMENT FUND :— | | | |
| £50 War Stock 1929–47, 5% at Cost | 50 0 0 | | |
| Cash on Deposit at Lloyds Bank | 17 7 6 | | |
| | | 67 7 6 | |
| SPENCE THOMAS SCHOLARSHIP FUND :— | | | |
| £1,250 Funded Loan 1960–90, 4 Per Cent. at Cost | | 1,000 0 0 | |
| | | | 6,473 19 11 |
| INSTITUTE BUILDINGS : Cost, exclusive of Furniture | | | 9,295 2 7 |
| NEW LIBRARY BUILDING : Cost, exclusive of Furniture | | | 4,455 14 6 |
| | | | £20,891 3 11 |

We have examined the Accounts and Balance Sheet with the Books and Vouchers of the Institute, and we report that the Balance Sheet is properly drawn up, and exhibits a true and correct view of the Institute's affairs as at December 31, 1919, as shown by the Books.

We have inspected the Securities and verified the Investments and Cash Balances.

McDONALD & REES,
AUDITORS.

CARDIFF, *March* 17, 1920.

agree that the duties of the position were admirably performed. (Applause.) **The President.**

The motion met with unanimous acceptance. Dr. H. K. Jordan, speaking in support, said he had known Mr. Price for a longer period, perhaps, than any one in the room, and had had exceptional opportunities of watching his career. He cordially endorsed the President as to the efficiency with which the secretarial work was done. **Dr. H. K. Jordan.**

## The Single-Field Cascade Machine.

By L. J. Hunt, M.Inst.C.E., M.I.E.E.

(Paper, *vide* Proceedings, Vol. XXXV., No. 2, p. 309.)

The President said the first Paper on the agenda for discussion was that by Mr. Hunt on the Single-Field Cascade Machine. The author had fully intended to be present at the resumed consideration of his interesting Paper, but had sent a telegram regretting his inability to carry out his intention. In the circumstances he (the President) thought it was desirable to further adjourn the discussion. **The President.**

## Coal Mining Leases.

By Hugh M. Ingledew.

The President said they had been favoured with a Paper upon a subject which he believed had never been discussed at the Institute. It was, however, a subject of great importance to the coalfield, and Mr. Ingledew was quite capable of dealing with it in all its phases. (Hear, hear.) They had all an appreciative recollection of his father, the late Mr. J. P. Ingledew, who in his day was a prominent solicitor in South Wales, and they were pleased to know that Mr. H. M. Ingledew was proving a worthy son of a worthy sire. (Applause.) **The President.**

# COAL MINING LEASES.

By Hugh M. Ingledew, Secretary to South Wales and Monmouthshire School of Mines.

# COAL MINING LEASES.

By Hugh M. Ingledew, Secretary to South Wales and Monmouthshire School of Mines.

The only excuse for attempting to deal with such a dull subject as Mining Leases is that some knowledge of their principles and application is essential to those who have entrusted to their care the control of large colliery undertakings, and in a smaller but no less important degree to the managers and engineers working under the directorate or principal agent.

The author would also like to say that as he is addressing the South Wales Institute of Engineers, he proposes to confine his remarks to mining leases in South Wales, and to say little or nothing about the peculiarities of mining leases in other parts of the country.

In saying this, however, it may justly be remarked that the principles underlying the settlement of a mining lease do not vary according to the different localities of the coal in respect of which the lease is to be granted, although the details and form of the leases are somewhat different in various areas.

It does not seem to be at all necessary, neither will it be expected, that he should enter into a detailed examination of the very debatable question of the ownership of royalties and the rights of mineral owners to grant the leases which have been so freely granted during the last hundred years over all parts of this country where minerals exist.

We have gathered from the proceedings before the Coal Industries Commission that, although the earth is the Lord's and the fullness thereof, the minerals do not appear to be His, but to belong to certain individuals who, according to the law of this country, are entitled to exploit them on reasonable terms for the benefit both of themselves and of the community at large.

Upon what principle this right is attacked as it has been attacked is not quite clear; neither is it clear to what extent the ownership of minerals and the right to make the best use of that ownership differs from the ownership of any other commodity or chattel, because, after all, a mineral once it is severed from the freehold or soil is a chattel exactly the same as a suit of clothes or a hat.

*Definitions.*—Before dealing specifically with the mining lease, it is useful to consider what the exact meaning of the various phrases appearing in those leases is.

The expression 'coal mine' has a twofold meaning: it is either (*a*) a passage through which the mineral is let or drawn underground or by which access is obtained to the mineral, or (*b*) the vein or seam itself.

The 'vein or seam' is a stratum of mineral.

'Mineral' is an inorganic substance forming part of the solid earth, and, as has been so truly remarked by Dr. Johnson, 'All metals are minerals, but all minerals are not metals.'

For instance, while a stone is a mineral, it is not a metal.

It is very often said, and the author believes on the authority of the immortal Mr. Bumble, that 'the law is a ass,' and a possible illustration of this axiom may be derived from the manner in which the English law treats clay, as it has not been able to make up its mind whether it is a mineral or not.

Under their special Acts, which incorporate the Railway

Clauses Act, 1845, and the Lands Clauses Act, 1845, a railway company is authorised to acquire land for the purpose of making a railway, but this acquisition does not include the minerals, unless there is a specific grant of the minerals in the conveyance.

Under the Railway Clauses Act, 1845, surface clay has been held to be a mineral, and excepted therefore from the ordinary conveyance to a railway company.

On the other hand, under the Waterworks Clauses Act, 1847, which is the Act under which water companies obtain their land for the statutory purposes of a reservoir, laying of pipes, etc., a bed of brick clay has been held not to be a mineral, and therefore is part of the property which the waterworks company acquire by implementing their compulsory powers for the purposes of their undertaking.

In Cornwall great doubt was expressed as to the exact position of china clay, which, as is well known, is worked from the surface, and after prolonged litigation it was decided, at the instance, the writer thinks, of the Great Western Company, that it was a mineral.

The word ' colliery ' or ' coalery,' as it was originally called, means seams of coal in industrial occupation.

The expression ' won,' in respect of minerals, means that the minerals have been reached in such a manner that continuous working can go on.

The expression ' workable,' in respect of coal, means workable at a profit.

*Deed of Severance.*—A colliery lease is a lease of the minerals only, coupled with such rights over the surface as may be granted as incidental and necessary to the working of the minerals, and is either in itself a deed of severance between the surface and the minerals or is a corollary of a prior deed of severance which may have been entered into.

Originally, of course, the surface and minerals were in the same ownership, the maxim of law being 'cujus est solum, ejus est usque ad coelum et ad inferos.'

The owner of the fee simple is entitled to do as he likes with his own property so long as he does not injure his neighbour, the maxim of law being 'sic utere tuo ut alienum non laedas,' and this underlying principle of law is applicable in the case of claims for damage by subsidence which we shall have to consider shortly.

The deed of severance under which either the surface is dealt with without the minerals, or the minerals are dealt with without the surface, produced the different ownership between surface and minerals.

It may be noted that whereas ownership by prescription or possession under the Statute of Limitations can be obtained of the surface, such ownership cannot, generally speaking, be obtained by adverse possession of minerals once they have been severed, even if they are not worked, the reason being that the law recognises that there is a continuing intention on the part of the owner of minerals to work and develop the same so soon as they become ripe for that purpose.

*Minerals under Foreshore, etc.*—The ownership of the surface of the foreshore between high and low water mark is vested in the Board of Trade, but the ownership of the minerals under the foreshore and beyond is vested in the Commissioners of Woods and Forests in the interest of the Crown.

It is a very noteworthy thing, in view of the controversy relating to profits on the working of coal which has recently taken place, that under the Crown Lands Act, 1866, which lays down the procedure for dealing with minerals belonging to the Crown, it is required that one-half of the net annual income on coal shall be applied to redemption of capital and the other half treated as income.

This seems to provide a statutory authority for the proposition that the prudent coalowner must set aside one-half of his net annual income as capital, namely, for renewals, developments, working capital, etc., on the ground, no doubt, that minerals are a wasting asset.

By the same Act it is provided that the owner of minerals under the sea is entitled to pass over and use the surface of the foreshore which belongs to the Board of Trade, in order to make pits, shafts, adits, and other works for the purpose of working the minerals.

With these few introductory remarks, it is proposed to now turn to the specific provisions of a South Wales mining lease.

1. *Parties and Plan.*—The first essential, of course, is for the lessee to know that he is obtaining his grant from the proper people, and that the area over which the grant extends is within the powers and ownership of the lessor.

It would naturally be imagined by reasonable people, who have not been compelled to enquire deeply into the subject, that the person who grants the lease is responsible for granting it, and for the area over which he grants it, but the unsuspecting lessee comes bang up against a big surprise at the very first step.

The law in its wisdom has laid it down that the lessee has no right to enquire into the title of his lessor, and although in most cases the solicitors for the lessee are able through the courtesy of the lessor's advisers and also through their own experience to obtain a pretty accurate knowledge of the adequacy of the title, it is none the less true that the lessee must, before he takes the lease, make up his mind whether he is satisfied that the lessor is the right person to grant him the lease, and he has to do this without having the legal right to enquire into the lessor's title.

After the lease is granted he cannot turn round on the lessor and complain of a defect in the lessor's title, and even if he is sued, and successfully sued, for trespass by the true owner of the coal which he is working, it is very doubtful to what extent he is entitled to call upon the lessor for an indemnity on the ground that he was working *bona fide* under powers contained in a colliery lease.

The same state of things exists with regard to the plan.

The colliery agent should make himself familiar from every source that he can with the ownership of the different properties surrounding his colliery, so that if opportunity occurs for acquiring a new taking to his colliery he may have a pretty good idea who it belongs to, and may be able to help his legal adviser in settling the boundaries of the plan.

2. *Demise.*—Care should be taken as to the description of the seams which are actually included in the lease, and here the colliery manager should be very familiar with the geological position of the different seams, not only in his own actual colliery but the corresponding seams at other parts of the same coalfield.

The broad division in South Wales is between the upper seams, extending from the No. 1 Rhondda down to and including the Abergorchy, and sometimes described as including all the seams down to the Cockshot Rock, and the lower seams or steam coal measures, which comprise all the seams under.

The best lease, of course, is to obtain a lease of *all* the seams under a certain farm, the boundaries of which are described in the lease, and also, but only by way of identification, in the plan, as it is always desirable that the exact boundaries of the property leased should be contained in the words of the lease, and that the lessee should not rely simply on the lease plan, which is often on a small scale and somewhat inaccurate.

If the lease does not comprise all the seams, then it contains

reservations in favour of the lessor of those seams under the given area which are not intended to be included in the lease, with proper rights to the lessor and his tenants of working same on making reasonable compensation for any damage which they may do.

It is, however, not an uncommon practice in South Wales that the lessor in granting an upper measures lease reserves to himself and his tenants the right of working the lower seams, and in so doing of letting down the upper measures by subsidence.

3. *Lessee's Powers.*—The lessee should take powers :

(*a*) To work and carry away the mines and beds of coal, ironstone, blackband and fireclay, and the stone and building stone.

Strictly speaking, the power to work does not include the power to carry away and market, and words to that effect should be inserted.

(*b*) Specific power to let down the surface in the course of working.

This is peculiarly necessary, because in the absence of such powers the mineral lessee may find himself faced with an application for an injunction at the suit of the surface owner to prevent the working of the minerals on the ground that such working is causing an interference with his Common Law right of support.

(*c*) Power to sink pits, drifts, openings, drive headings, etc.

(*d*) Power of instroke and outstroke.

This is a most important power, and should be contained in every lease, especially that which does not contain powers to make openings from the surface. The right of instroke is inherent in a lessee unless the wording of the lease expressly forbids it, but there is no such inherent right of outstroke.

The right of instroke is a right of conveying minerals from a demised mine to the surface through a pit or shaft in an adjoining mine.

The right of outstroke is the converse, and consists in the right of conveying minerals from an adjoining mine to the surface through a pit or shaft in the demised mine.

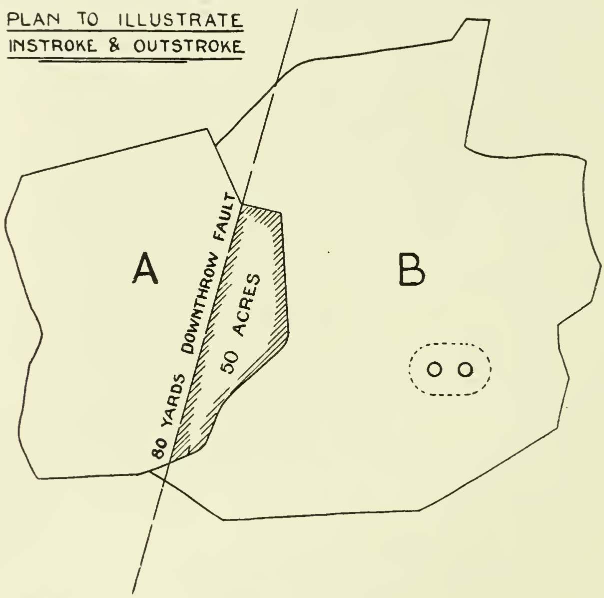



Fig. 1.

It will be seen, therefore, that the words are really a paradox, and that instroke is really the right of taking the demised coal outwards into another property, and outstroke is the right of taking adjoining coal inwards through the demised property. Fig. 1 illustrates what is meant, and the advantage of powers of instroke where the demised property A is cut off by a big fault.

(*e*) Power of wayleave with or without payment.

Fig. 2 shows a number of properties in the Glamorganshire district which might be conveniently worked together,

and the importance of providing in such cases for there being no wayleaves in small properties, as some of the

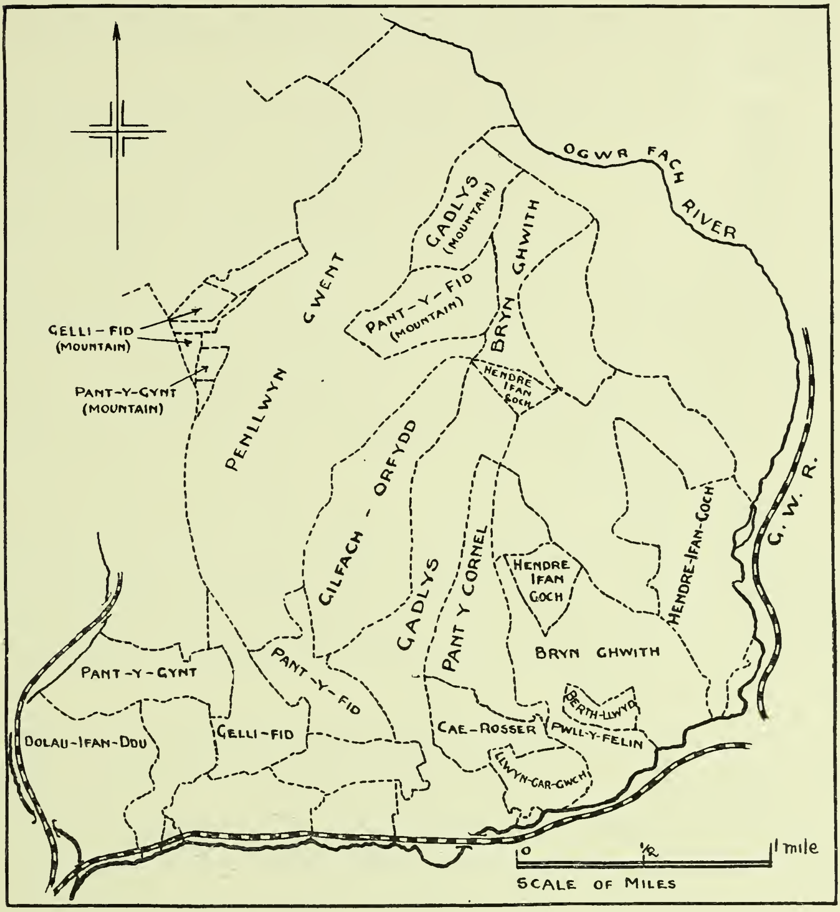



FIG. 2.—Map to Illustrate Combined Royalty Takings.

more distant coal might have to pay four or five wayleaves before it got to the pit near the Great Western Railway on the right-hand side.

The author has found in his experience that under similar circumstances landowners are only too ready to realise the geographical conditions, and either impose no wayleave or

purely a nominal wayleave, and in some cases the colliery manager or solicitor is able to arrange that one landowner is willing to grant freedom from wayleave to adjoining coal if the owner of the adjoining coal is willing to grant a similar concession.

It is perhaps needless to say that care should be taken to prevent the imposition of a wayleave on the demised coal passing through the owner's own property (except a surface wayleave for a railway), and to avoid a double wayleave both under and above ground creeping into the lease. Some landlords are willing to agree that the wayleave, like the royalties, shall merge in the dead rent, but this is the exception.

(*f*) Power to erect buildings, coke-ovens, patent fuel works, brick works, and machinery, both overground and underground.

These are important powers which the colliery manager should carefully consider and which should be specifically granted. Especially are they important in these days when the value of by-products has come so prominently to the front.

(*g*) Water rights.

This is a power which is very often overlooked, but which is most essential for the economic working of the boilers, condensers, and washing plant, and may save the colliery proprietor large sums every year if properly provided for. These powers are generally subject to the agricultural tenant having 'first drink,' and in some cases to prior rights granted by the lessor to others.

(*h*) Surface rights.

The general practice in South Wales is to pay an annual sum per acre, which varies from £2 to £3 per acre, or to pay a lump sum for each acre occupied at the rate of, say, £60 an acre, which is practically a commutation over the sixty years of the annual payment.

Most leases contain powers for surface works and particularly for tipping ground, and recent experience has shown the necessity for the colliery manager being especially careful in selecting the site for the big colliery tips, and it is suggested that an initial capital expenditure attached to a safe site may perhaps be cheaper in the long run than a saving of money in the selection of a nearer and more easily accessible site.

The general principle of law is not in dispute, viz., that a colliery tip is in the same position as a wild animal, and that the person who brings a wild animal on to his land must keep it in proper confinement and prevent it through anything inherent in itself from doing damage to his neighbour; in other words, if the colliery proprietor constructs a large refuse tip and the refuse tip takes it into its head to walk into its neighbour's garden or over its neighbour's house, the colliery proprietor will be subject to litigation for damages, and he will have to show that the movement of the colliery tip was caused by natural causes and matters over which he had no control or responsibility.

(*i*) The lessee takes power to remove tenant's fixtures and machinery at the end of the term, and there is as a rule a proviso that all liberties are subject to rights and liberties which have been previously granted by the same lessor.

4. *Term.*—The usual term is sixty years, although some of the older leases were granted for ninety-nine years.

5. *Dead Rent.*—The usual practice in South Wales is to charge £1, £2, or £3 per acre, according to the circumstances and the seams let.

Where the seams are let separately it sometimes happens that the landlord is lucky enough to get £2 on each lease, and

he may therefore get £6 or even more per acre on the minerals under the same surface.

It has been said that the object of a dead rent is to act as a whip to the working lessee, but in the author's experience the working lessee never requires such an inducement, and on his part looks on the dead rent as an iniquitous burden which the landlord by a kind of prescriptive right is enabled to impose upon him.

On the other hand, where the landlord is satisfied that the lessee in spite of every effort and diligence is unable to make his dead rent and shorts accrue, the landlord in many cases grants concessions and remits arrears of dead rent in favour of the lessee, and this has been done to the amount of many thousands of pounds and is greatly to the credit of the great landlords of this district and their agents.

6. *Surface Area.*—The area is generally specified on the plan or has to be agreed on with the landlord's agents.

7. *Royalties.*—These are either fixed or variable.

The fixed royalty on through coal varies from 4*d.* to as high under modern conditions as 1*s.*, but an average of 7*d.* to 9*d.* is more usual. The tendency of the Coal Control and other Government interference has been to substantially increase the royalties asked.

A common royalty was 8*d.* on large coal and 4*d.* on small, which is equivalent to $6\frac{2}{3}d.$ through coal where the percentage of large is 66 per cent., and something less where the large coal does not amount to that figure, but these figures are on the upward grade.

All modern leases are based upon the statute ton of 2240 lb., but thirty, forty, and fifty years ago it was most common to have the royalty based upon the long ton of 2520 lb., which meant that the royalty was nearly one-ninth less than the corresponding figure based on a statute ton.

Large coal is described in the lease as coal which has not passed through a screen of $1\frac{1}{8}$ in. mesh, and as is well known the workmen in South Wales are paid on large coal.

Some landlords insist on a sliding scale payment, varying according to the selling price of the coal, and under the present abnormal conditions of prices the scale results in royalties of 2*s.*, 2*s.* 6*d.*, and even higher being payable. It is not uncommon in such cases for some concession to be asked from the landlord, and it is very rarely refused.

The lessee should always be granted an allowance free of royalty in respect of colliery consumption. The more convenient practice is to grant a fixed percentage of the output up to 5 per cent., and in very special cases even over this figure. Where the allowance is on actual consumption, it is usual to provide that a proportion of the coal used for power for adjoining minerals shall be debited to those minerals.

8. *Payments.*—The payments for rents, royalties, way-leaves, etc., are made half-yearly, free from all deductions except landlord's property tax and mineral rights duty.

Fig. 3 shows the respective relations between collieries nearer the ports and collieries farther away from the ports, and the colliery agent should always recollect that if his mineral area is farthest from the port he is handicapped to the extent of the additional railway rate as compared with coal nearer the port. The increase in transport charges has emphasised this.

9. *Average Clause.*—This is a most important point for the colliery manager to consider.

The average clause may be :

(*a*) Over the whole term.

(*b*) Divided into watertight periods of fixed periods, say, five or ten years.

(*c*) Running periods.

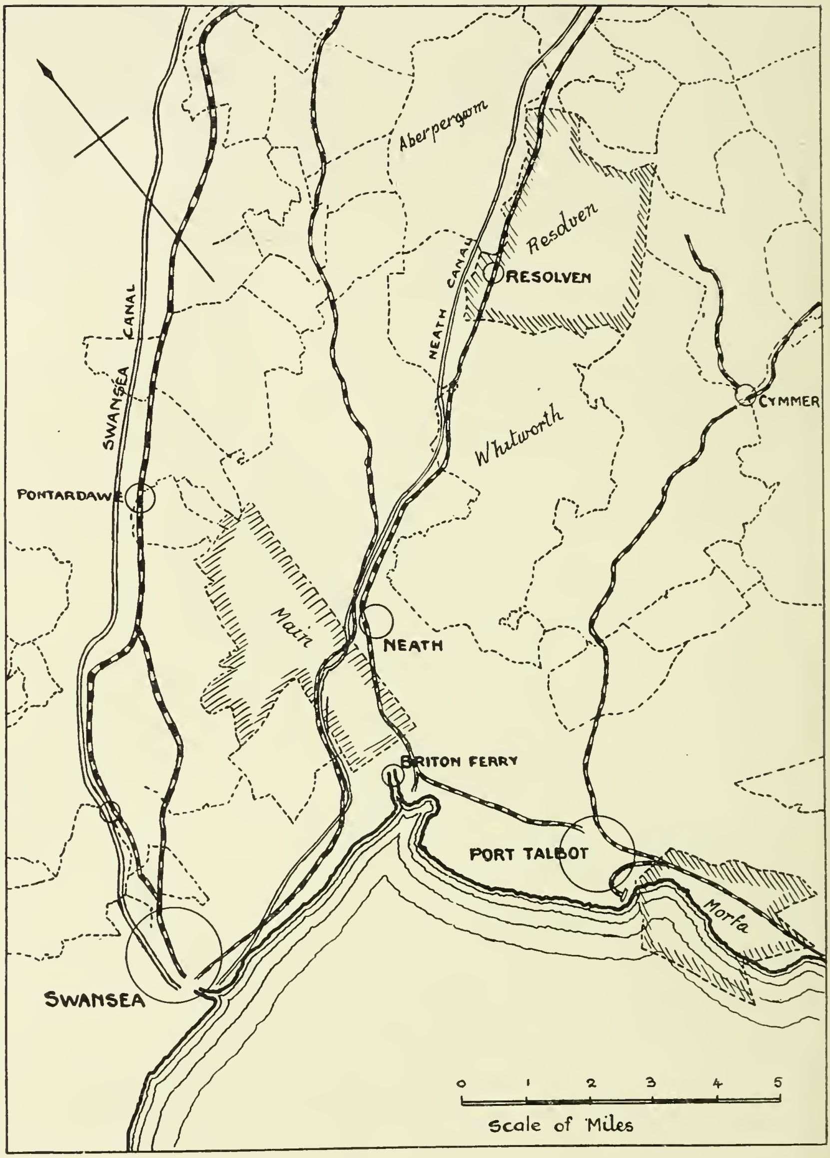



FIG. 3.—Position of Colliery Takings in Relation to Ports.

The average clause may be said to be a clause in favour of the lessee, and the object is that where he is unable to make his dead rent either in the earlier years whilst he is developing, or subsequently owing to mining difficulties, faults, or other causes, he should have an opportunity of making up his dead rent from the royalties of subsequent years.

It is suggested sometimes that a short average clause is in favour of the lessee on the ground that it induces rapid development, but the other side of the question is where the landlord insists on terms in his lease which prevent the possibility of a lessee receiving the shorts in respect of the dead rents which he is compelled to pay. Such cases seldom happen.

The fair principle, assuming that the dead rent is an adequate one of course, is that the lessee should be entitled to average over the whole term of his lease, but in most cases the landlord is not willing to agree to this, although the tendency in modern cases is in this direction.

The colliery agent or manager should in taking the lease carefully consider how long it will be before his workings will reach the leased property, and he will be able to make his dead rent.

If he is taking a property some little distance away from his existing workings, or where he knows he will have to make a new sinking, he asks for a first fixed period which has regard to the time that it will take him to reach and work the minerals.

This fixed period generally varies from seven, ten, or even up to fifteen and twenty years.

For the remainder of the lease the term is divided sometimes into fixed watertight periods for five years, each period of which stands by itself for the purpose of average, or more frequently into running periods of three, four, five and occasionally seven years.

The running average clause provides that if there is a deficiency in any given year the lessee may make it good in

one of the two, three, four or following years as the case may be, and it should be noted that a right to make good a deficiency in the two following years is a three years average clause, and to make good the deficiency in the four following years is a five years average clause.

It should also be noted that the right to average is in respect of subsequent years only, and that it is very rarely that the right to go backwards and forwards for average purposes is granted to the lessee.

10. *Lessee's Covenants.*—It is unnecessary to go through all the minor covenants which are inserted in a lease, such as to pay rent, taxes, leave pillars, leave barriers, not to allow water to accumulate, fencing, repair and maintenance, compensation to tenants for damage by fire, weighing, keeping records of weights, keeping accounts, plans, give the landlord inspection, and matters of that kind, but there are two or three important questions to which attention should be drawn.

11. *Working Clause.*—The careful colliery agent and manager will pay special attention to the wording of this clause, especially where he is taking a property in what may be anticipated to be a disturbed district where faults and other mining disturbances may be met.

In a sense the working clause covers most of the covenants by the lessee with which a modern mining lease is burdened.

The landlord generally asks that the lessee should covenant to work the property continuously and vigorously in accordance with the most approved practice of the county of Glamorgan, etc., and so as to extract the whole of the coal which can be commercially and profitably worked.

Objection is generally taken to come under any obligation to work continuously, as although it is probably a compliance with this covenant if a few tons a day are worked from the leased undertaking, yet the lessee always has the sword of Damocles over his head in respect of a claim by the landlord

for compensation for loss of royalties owing to the small quantities worked.

A lessee with the best intentions may, owing to difficulties in working, be from time to time stopped, and he ought to object to come under any obligation to work continuously, although he should not object to work vigorously.

The lessee should in respect of a small property forming part of a large colliery also qualify his working covenant by words making it clear that he is working the particular property in question in order or rotation as part of his general colliery undertaking, and that he is not covenanting to work the particular property to the exclusion of proper mining and proper development of the colliery as a whole.

12. *Compensation for Surface Damage caused by Subsidence.*—It has already been pointed out that the lessee should in every case take a specific power to let down the surface by the withdrawal of either vertical or lateral support caused in the working of the minerals.

The law with regard to subsidence is pretty well settled, and it may shortly be described as follows:

The owner of the surface or of any building on the surface has a Common Law right of support both vertical and lateral unless there has been a severance as between surface and mineral, and in the deed of severance the owner has granted a specific right to let down the surface without making compensation, either by specific words or by necessary implication.

It has also been held that the working of minerals in a proper mining manner, even if they cannot be worked without letting down the surface, does not relieve the lessee from the above obligation, and does not give him by necessary implication a right to let down the surface.

The lessee must have received a specific grant for the purpose, and it will therefore be seen how important it is to have proper words in the colliery lease.

The modern practice is that the lessee should only accept liability for compensation to buildings existing on the surface at the time of the granting of the lease, and that if the landlord wants to grant further surface leases he ought to protect his mineral lessee by inserting in the surface lease proper provisions depriving the surface lessee of the right to compensation for subsidence caused by the mineral workings.

There is nothing unfair in this, as the surface lessee in most cases earns his living out of the working of the colliery and is dependent upon the success of the colliery for his maintenance and living, whereas it is unfair to the mineral lessee who has developed the surface owing to the expenditure of his capital on the mineral workings that he should absolutely be fined for such development by means of a claim for compensation for subsidence which cannot be avoided owing to the energy of his work and his enterprise, in other words, that he should be penalised for the values of which he is himself the creator.

It has been suggested that there should be a common fund raised upon the output in each district, administered by an independent tribunal with power to settle relative values and prevent injunctions, coupled with a general insurance fund to provide compensation for damage. Such a scheme is attractive on the surface, but presents great difficulties in practical operation, owing to the divergent circumstances of the different collieries even in the same district.

The other point arising out of subsidence falls under what is known as the *Howley Park judgment.*

Prior to 1912 it was always understood that the law relating to railway companies was that a railway company was protected to the extent of the clauses in the Railway Clauses Act, 1845, relating to 40 yards and not otherwise. This 40 yards was based upon an assumed depth of 200 yards to the minerals, deep working as now existing being then unknown.

These clauses provided that where a mineral lessee was

approaching a railway he should give notice to the railway company that his workings were approaching or had approached the 40 yards limit, and the railway company then had to decide whether they would buy the coal within the forty yards and under their railway, or run the racket of the damage.

Except in cases of important works, such as tunnels, heavy viaducts, or stations, it has been usual for the railway companies to make good the subsidence and prop up their railways instead of buying the coal.

In 1912 the Howley Park case decided that irrespective of the mining code in the 1845 Act relating to the 40 yards, a railway company had their ordinary Common Law right of support outside the 40 yards.

This created a great outcry, as it was felt that colliery proprietors would not know where they were, and that it would tend to a sterilisation and non-working of minerals.

Proper steps would have been taken by the Mining Association to bring in a Bill to amend the law, had not the war come on in 1914, but recently, at the instance of Mr. Leslie Scott's Land Acquisition Section of one of the Reconstruction Committees, meetings have taken place between representatives of the coal owners and the railway companies, as the result of which a provisional agreement has been come to, to get over the difficulty, the short effect of which is as follows:

1. In respect of heavy works, viaducts, etc., which require a pillar of coal to be left for their support, the suggestions are:

(*a*) That where the mine owner has arrived at a distance equal to one-half of the depth of his seam from the surface, he shall give to the railway company thirty days' notice that his workings are approaching the railway.

(*b*) The railway company on receipt of such notice will decide whether they will require a pillar to be left and

what pillar they require in each seam, and also the particular length or part of the railway intended to be supported by the reserved pillar. The mine owner is to be free to work all the coal not contained in the pillar without liability for support.

(*c*) The railway company will pay for all the coal in the pillar thus left on the following footing:

(1) In respect of the coal within the 40 yards prescribed by the Railway Clauses Act, 1845, the payment shall be the amount per ton either agreed or settled by arbitration under the 1845 Act.

(2) In respect of the coal outside the 40 yards, *i.e.* Howley Park coal, the railway company will pay one-third of the assessed price of the same coal within the 40 yards.

2. In respect of the line of railway where there are no big works and therefore no necessity to reserve a pillar, the mine owner will be required to pay a proportion of the cost of maintenance arising from subsidence.

This payment will be according to a scale which provides for no payment up to 160 yards; 3 per cent. from 170 yards, rising each 10 yards to 60 per cent. at 650 yards deep and over, with a maximum liability of 6*d.* per ton, which is calculated to be sufficient to last over a period of thirty years.

Fig. 4 shows on a section the difference between the 40 yards coal under the 1845 Act and the additional pillar required under the Howley Park judgment.

13. *Surrender Clause.*—The lessee should be very careful as to the wording of this clause.

It should be clear that either at the end of a fixed period, or if the mine, after a reasonably full trial, is unworkable at

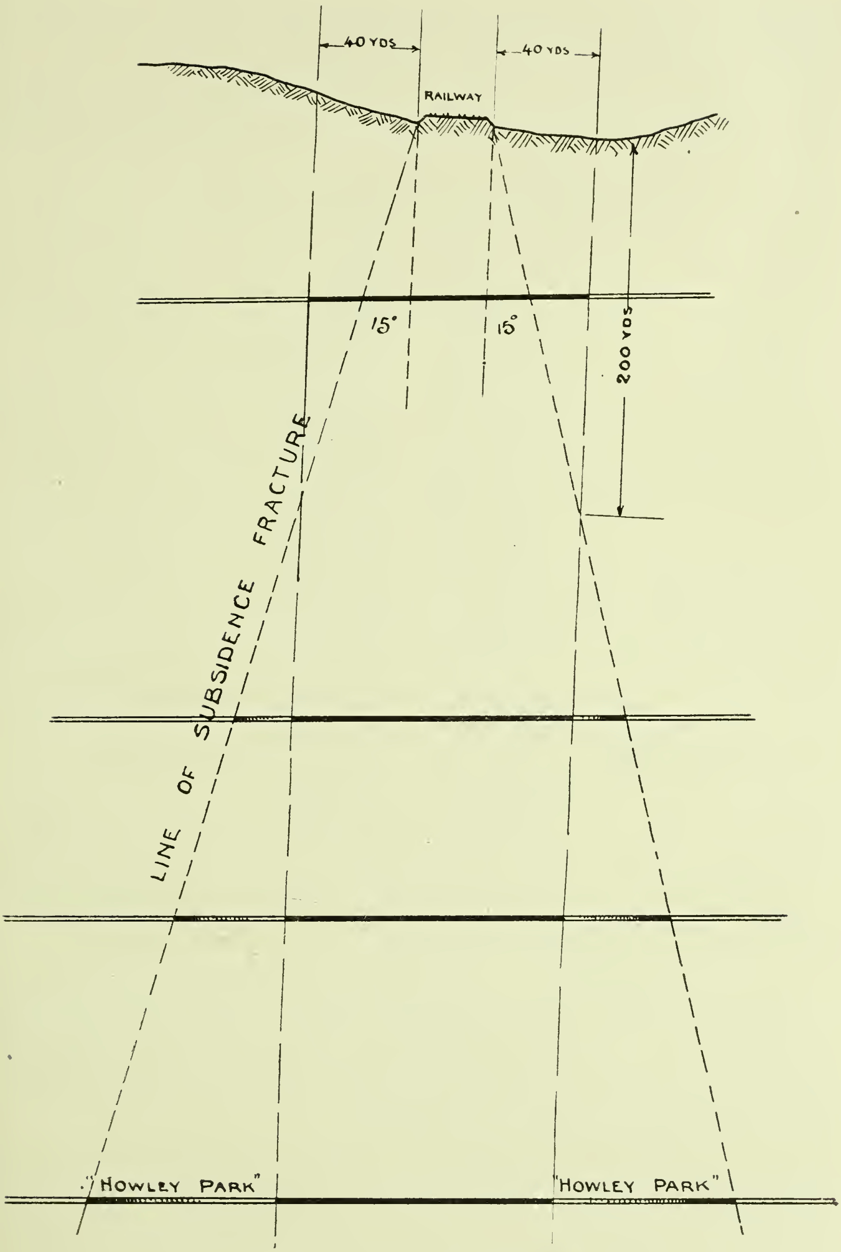



FIG. 4.—Support of Railway.

a profit, he has a right to surrender the lease and escape all further liability on twelve months' notice.

It should not be a condition of this surrender that the lessee has complied with all the covenants and conditions in the lease.

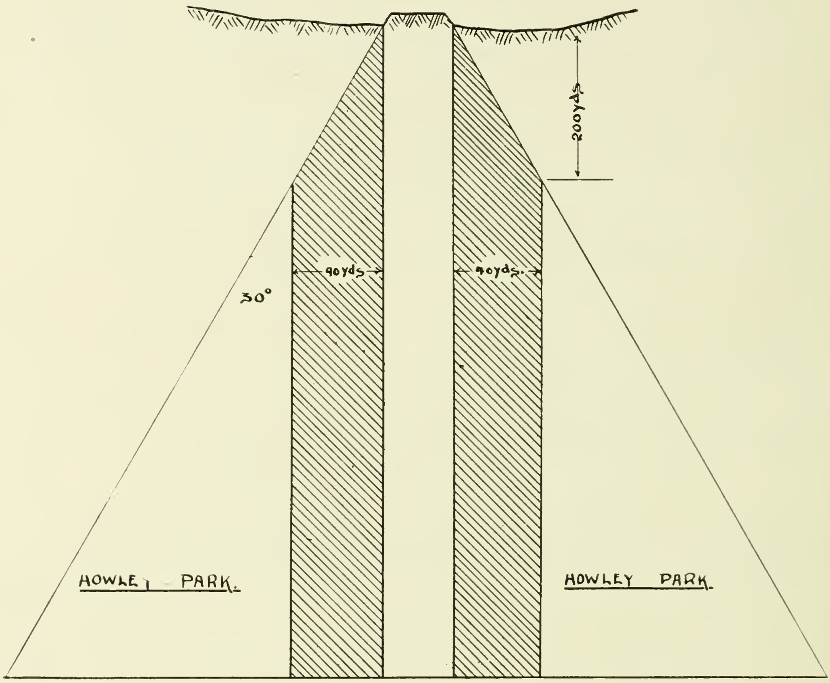



Fig. 5.—Support of Railway.

*Note.*—This Diagram is by way of illustration only, and does not purport to be drawn to scale or to contain correct angles of draw.

It should be sufficient that he has paid all the rents and royalties, and that if the landlord thinks he has a claim for antecedent breach of covenant those rights in respect of that breach are reserved to the landlord.

14. *Landlord's Pre-emption of Machinery and Plant.*—It is generally provided that there is a right of pre-emption in favour of the landlord to the tenant's machinery and plant in the colliery on the termination of the lease, either by effluxion of time or otherwise.

It is sometimes provided that the right of the landlord to purchase this plant is based upon scrap value or, as it is termed, the value for removal, which means the value *in situ* less the cost of removal.

It is submitted that this gives an unfair advantage to the landlord who does not intend to remove the plant in fact, but intends to use the plant as part of the going concern, although he has bought the plant at the price of a derelict concern.

The landlord claims that he only ought to pay what the plant would fetch in the open market for removal. The tenant claims that where the plant is not intended to be removed but to remain *in situ* as part of a going concern, he ought to be paid on that basis. If the arbitrator is unfettered he can value according to the facts of each case.

The fair basis of price should be by means of agreement or a simple arbitration, in which case the arbitrator should be free, if circumstances warrant it, to give the lessee a price based upon the value of the plant as a going concern.

15. *Trespass.*—This is a matter which in a fully occupied district like South Wales the colliery manager must always keep his eye on, and he must be careful not to place too great reliance upon the lease plan, which in most cases is on a very small scale and sometimes somewhat inaccurate.

He should rely upon the exact survey made by his surveyor.

In case of trespass the principle of law is quite clear, viz., that the trespasser is liable to pay to the owner the value of the coal which has been improperly taken.

The value of the coal is, however, arrived at on a different basis, according to whether the trespass was deliberate and reckless, or whether it was inadvertent or as a result of miscalculation, incorrect plans, or some other cause of that kind.

In the case of a wilful trespass, the damages are assessed on what is known in the Chancery Court as the 'harsher rule,'

that is to say, the trespasser has to pay the value of the coal at the pit bank less only the cost of bringing the coal to bank, the cost of working being disallowed.

Under the milder rule, which is applicable where the trespass is inadvertent, or at any rate something far less than intentional or reckless, the trespasser is liable to pay to the owner the value of the coal less the cost of severance and less also the cost of bringing it to bank.

It will be seen, therefore, that in case of a deliberate trespass the trespasser is fined the whole of the cost of severing the coal, that being the illegal act, but is allowed the cost of bringing it to the pit top, and the general experience of the cost of colliery working shows that the cost of severance is a serious matter, involving a minute examination of the cost of working, which was fully inquired into in Phillips *v.* Hombray, 1871, L.R. 6 Ch. App. 770.

The author does not pretend to have dealt in this short Paper with more than a bird's-eye view of the main principles which should be borne in mind in dealing with the different matters which arise on a colliery lease; in fact it would be impossible in the time at his disposal so to do.

The subject is full of interest and is well worthy of your further consideration and research.

On the subject, for instance, of sea-borne coal, it is well known that the Stockton and Darlington railway, authorised in 1821, was the first practical railway as we understand it in the country, and it is interesting to note that the original Act contained a preference in favour of the export trade, as the rates on that railway on coal for shipment were substantially less than the rates on inland coal, a difference which is continued to the present day, not only in that district but also in the South Wales district.

In the Newcastle and Durham coalfield Mr. E. M. Hann

has told the author that originally royalties were reckoned in tens, not in tons, and that ten was $48\frac{2}{3}$ tons, and was a measure of so many Newcastle cauldrons.

Also wayleaves in that district at that time used to be subdivided into thirds, under the names of wayleave, air and water leave, and shaft leave, and thus only the man who was the owner of the shaft area got what is commonly now known as a wayleave, the others got one-third or two-thirds, as the case might be.

In South Wales at the present time the shaft leave or shaft wayleave as such is rarely found, and there is a good deal to be said for the proposition that the shaft wayleave if it is charged should be a charge in favour of the working lessee, who has spent his capital on making the shaft, rather than of the wayleave owner, who has granted the lease and imposed an obligation on the lessee to construct the shaft.

The matter is, however, not one of very serious importance.

There is one question which is worthy of consideration as a practical proposition to those controlling the mines, and that is as to what extent adjoining properties can make common use of a pair of shafts.

So far as the author knows there is no case in South Wales where two separate colliery owners use one shaft, which actually belongs to only one of them.

On the other hand, the point had come forward in practice on more than one occasion, and there is no real difficulty in making in legal form an arrangement which would provide for a fair sum for rent and proportion of maintenance and renewals to be paid to the owner of the shaft by the adjoining owner that is making use of it, and thus save the very heavy expense of duplication of sinkings.

There are other little items where improvements might be made in the terms of the lease in favour of the colliery

proprietor; for instance, the author has never been able to understand why the lessors should insist that the payment of royalties should be based upon the weight of the tram as it came up to the pit top, including as it does a certain proportion of dirt.

With the modern improvements in the shape of washing it seems more proper that the working lessee should have the benefit of his enterprise in that respect, and thus only pay the landlord a royalty on what is actually coal, and should not be compelled to pay the landlord a coal royalty on what is actually dirt, and there is little doubt that in the course of time this will be recognised by the royalty owner.

The lessee, as Mr. William Jenkins of the Ocean Company has pointed out to the author, is generally a good-natured animal, ready to accept within limits anything put before him, and desirous so far as possible of avoiding disputes with his landlord.

It is perhaps from that good-humoured commercial attitude which is so necessary a qualification for success in business that the lessee has been willing to put up with the insertion in his leases of clauses which, if challenged in the cold light of logic, could hardly be sustained before an impartial tribunal, but at the same time it is undoubted that, speaking generally, the royalty owners of South Wales are keenly interested in the success of the great coal trade which through their highly capable agents they have assisted in building up, and there is a very widespread good feeling existing, as it ought to exist, between the royalty owner on the one part and the colliery lessee on the other part.

Such a feeling is a good augury for the future and the continued success and development of the great industry of this district.

## Discussion on Mining Leases.

Mr. WESTGARTH FORSTER BROWN, opening the discussion, said he had not had time to read the Paper very carefully, but he had perused it with deep interest, and he was sure they all felt obliged to Mr. Ingledew for having brought the subject of mining leases before the Institute. The author had described the subject as being dull; but when they recalled how full of surprises was the law of mining, the subject could scarcely be called 'dull.' When they thought the law of mining laid down one thing, it frequently turned out to be something totally different. The Paper was an exceedingly useful one, especially, perhaps, to the mineral lessee, who was therein put up to all the wiles of the mineral agent. (Laughter.) It also afforded information to the mineral agent, for did it not tell him that the mineral lessee was so good-natured he was ready to accept anything the mineral agent sought to impose upon him? (Laughter.) Mr. Ingledew referred to minerals under the foreshore. No doubt the author was perfectly right as to the legal position, but in practice it was often the case that the Crown had parted with its rights either by charter or through acts of ownership by adjoining owners, so that it did not invariably follow that the Crown possessed the minerals under the foreshore. There was also a little reservation to be made as to the use of the surface of the foreshore. The author said: 'By the same Act it is provided that the owner of minerals under the sea is entitled to pass over and use the surface of the foreshore which belongs to the Board of Trade, in order to make pits, shafts, adits, and other works for the purpose of working the minerals.' As a matter of fact, the Board of Trade had the power to interfere with the works of a lessee on the surface in the interests of navigation. He knew of one case in which this interference took place after a pit was Mr. Westgarth F. Brown.

**Mr. Westgarth F. Brown.**

sunk because of the presence of a surface wall which was deemed to prejudice safe navigation. The author of the Paper expressed the opinion that the best lease was a lease of *all* the seams. That depended upon the point of view. Mr. Ingledew's opinion was, no doubt, the correct one in the mineral lessee's interests, but the mineral owner and the community would probably think differently. Take the South Wales district, for instance. In the case of a company mainly concerned with steam coal, but possessing a lease of all the seams in the taking, the temptation would be to leave the bituminous coal above, which, however, under separate leases, would be worked for the benefit of the community and the landlord. Otherwise, he quite agreed that from the mineral lessee's point of view it was nice to have all the seams and no possible interference from other people. With regard to the average clause, he had always held the view, when mining enterprises were not on the big scale to which they had developed, that a short term average clause was advisable if they were to prevent properties being locked up in the hands of speculators. In those days of deep mining and very large collieries it was not worth anybody's while to do that sort of thing; but the operation of the short term average clause in the past had induced rapid development, and was generally beneficial in its effects. In his reference to the clause for continuous workings, Mr. Ingledew had omitted to state that it was usual to insert a reservation as to strikes, or any circumstances over which the lessee had no control. With such a reservation, the lessee could not be subjected to such annoyance as the Paper indicated. On the question of the support of the surface, the author said the modern practice was that the lessee only accepted liability for compensation to buildings on the surface at the time of the granting of the lease. That was doubtless the position where the surface and the minerals were in the

same hands, but where the surface rights were severed there was often a difficulty arising from the fact that the surface owner had the power to injunct the working of the minerals. That power had led to a good deal of loss of coal at one time or another. That question had been before Mr. Leslie Scott's Committee, who took the view that if a good case could be made out that the minerals were worth more to the community than the support of particular buildings, etc., on the surface, there ought to be a tribunal to settle the relative values and compel the working of the mineral if it was in the interest of the community that this should be done. On the other hand, the surface owner was entitled to compensation for being deprived of his right of injunction, and the Committee suggested an Insurance Fund, to be contributed to by the mineral worker and the surface owner, and possibly the mineral owner, and guaranteed by the State, out of which this compensation should be paid according to the estimate put upon the forfeited rights by the tribunal. He did not think that question had been much discussed by mining people, but its importance called for due consideration, and that was why he had now raised it. The author of the Paper had called attention, in reference to the subsidence question, to the Howley Park judgment. Now, that was one of the surprises of mining law to which he alluded at the opening of his remarks. For sixty years or more they had thought the law to be one thing and it turned out to be something very different. No doubt when the original Railway Clause Act was drawn up 40 yards was thought to be sufficient. He noticed that Mr. Ingledew made the statement—and he should like to know whether it was simply his opinion or whether it was contained in any Act—that this 40 yards was based on an assured depth of 200 yards to the minerals. If this assumption was deliberately arrived at, he should like to know if the framers of the Act Mr. Westgarth F. Brown.

Mr. Westgarth F. Brown.

had any figures bearing on the point before them, or whether a general deduction that mining outside 40 yards could not affect the surface. The recent attempt to settle that problem by Mr. Leslie Scott's Land Acquisition Committee, one of the Reconstruction Committees, was one with which one of their Past Presidents, Mr. Hugh Bramwell, had much to do, and had resulted in a fair compromise. He was sorry it had not yet been carried into effect, but it might yet be done. There was one omission he noticed in the Paper. It contained no reference to a Consumption clause. It was usual in mining leases to grant a certain amount of coal free to cover colliery consumption, especially where the royalty was fixed on the pit top weight. There were other points on mineral leases he could speak upon, but he did not want mineral lessees to know all his pet arguments. (Laughter.)

The President.

The PRESIDENT : Mr. Bramwell ?

Mr. Hugh Bramwell.

Mr. HUGH BRAMWELL : I have nothing to say, Mr. President.

Mr. C. S. Morris.

Mr. C. S. MORRIS said the author of the Paper indicated the upper seams of the coalfield as 'extending from the No. 1 Rhondda down to and including the Abergorchy, and sometimes described as including all the seams down to the Cockshot Rock.' That, he (Mr. Morris) thought, referred only to a portion of the coalfield. The author suggested that the lessee should obtain power to work and carry away the stone and building stone. In his (the speaker's) experience the stone was not generally included in the demise, but power was often given to a lessee to work stone. That would not prevent the lessor from also quarrying stone for himself and his surface tenants. With regard to the payment for wrongful trespass, surely the only allowance made from the value of the coal was the cost of the carriage of the coal from the point of severance to the point of sale. Mr. Ingledew suggested that severance was allowed.

Mr. INGLEDEW : Not severance. I do not suggest that. Mr. Ingledew.

Mr. MORRIS (continuing) said he understood the Courts had decided that the only allowance was the carriage of the coal from the point of severance to the point of sale. Would Mr. Ingledew say from when the Statute of Limitations commenced to run—whether from the date of the actual trespass or from the date of its discovery. Mr. Morris.

Mr. INGLEDEW : From the date of discovery, I think. Mr. Ingledew.

Mr. J. FOX TALLIS said they were very much indebted to Mr. Ingledew for his very interesting Paper, the subject of which, as the President had observed, was new to the Institute's 'Proceedings.' The Paper contained many valuable hints, of which they ought to take full advantage, especially, perhaps, in view of all the talk just now about the nationalisation of minerals. Dealing with the subject of minerals under the foreshore, the author said : 'It is a very noteworthy thing, in view of the controversy relating to profits on the working of coal which has recently taken place, that under the Crown Lands Act, 1866, which lays down the procedure for dealing with minerals belonging to the Crown, it is required that one-half of the net annual income on coal shall be applied to redemption of capital and the other half treated as income.' That reminder should be a warning to colliery companies, particularly in South Wales. He would like to know how many colliery companies in South Wales would be in a position, when their seams were exhausted, to pay to their shareholders the value of their shares or the money they had invested. He was afraid very few colliery balance-sheets in South Wales showed that the investors could be repaid the money they had put into the concern ; and it was time that matter was taken up in earnest, especially in view of the attitude of certain parties in the State towards the question of the ownership of the mines. The author had described very clearly the power Mr. J. Fox Tallis.

Mr. J. Fox Tallis.

of instroke and outstroke. It was very evident that one without the other was of very little value. Take Fig. 1 in the Paper. Colliery owner 'B' wished to work 50 acres of the adjoining taking, which was severed by a large fault. In order to do that it was necessary he should have the power of outstroke in order to bring that coal from the other colliery up his own shaft. At the same time if he was going to make an exchange of that kind for the purpose of straightening the boundary, he must have also the power of instroke. It would be seen in Fig. 1 that there were two small areas of 'B' colliery on the left-hand side of the fault. The lessee of 'B' could not get the coal from those areas without going to colliery 'A' and having the right of instroke. With reference to the power of wayleave with or without payment, it was a very vexed question whether it was justified or not. So far as he could see, a wayleave hit the lessor more than it hit the lessee. Of course, where the mineral taking was close to a railway the property was much more valuable to the lessor and enabled him to demand a wayleave; the lessee of an inside property situate a long distance from the shaft could only pay the owner a small royalty because of the number of wayleaves he had to pay, and the cost of increased haulage before he could get the coal to the shaft. As to dead rent, that was an important matter in drafting the covenant. Take the case of a property close to the bottom of the shaft with a fixed dead rent and a wayleave, and only one seam leased. The same argument would apply to a number of seams, but for the sake of simplicity he would take one seam. It was situate close to the bottom of the pit. In the ordinary course of working they took all the coal out in front of them in the course of a few years, but they still required that property for bringing coal from other properties, inside. It was very unfair that the lessee, after he had exhausted the coal in the property close to the shaft, should

be compelled to continue to pay dead rent and wayleave. In such an instance, the lessee should have the power of stopping payment of dead rent when the coal was exhausted, or have an arrangement by which he paid only a nominal rent or wayleave. The author had referred to a sliding scale payment of royalty. That method had acted unfairly because it did not take into consideration increased costs of working. If they had a sliding scale system at all it should be on profits and not on the selling price of coal. The author went on to say, 'The payments for rents, royalties, wayleaves, etc., are made half-yearly, free from all deductions except landlord's property tax and mineral rights duty.' He (Mr. Tallis) was not aware that a lessee paid mineral rights duty in any case; he always thought it was paid by the lessor. As to the average clause, that was very important. Mr. Forster Brown had said the short term average clause had induced a rapid development of the minerals. There was no doubt something in that, but had it always worked entirely to the benefit of the lessee? Had it not been rather the cause of working seams of coal one underneath the other simply for the purpose of recovering the dead rent? He knew from his own experience that more collieries in South Wales had been ruined by working two or three seams one underneath the other than from any other cause. The proper method was to work one seam at a time when they could do so, but when there was an average clause and the dead rents were increasing they would stretch a point in order to get back the dead rent. In his opinion, the only fair average clause was over the whole term. The landlord was sufficiently protected by a working clause in the lease demanding that the coal should be worked in a proper manner and in due time. Mr. Ingledew said: 'In the case of a wilful trespass the damages are assessed on what is known in the Chancery Court as the "harsher rule"; that is to say, the trespasser has to pay the value of the coal

**Mr. J. Fox Tallis.**

Mr. J. Fox Tallis.

at the pit bank less only the cost of working.' The word 'working' was very deceptive, and had caused a good deal of misapprehension.

Mr. Ingledew.

Mr. Ingledew: It should be 'severing.'

Mr. Fox Tallis.

Mr. Fox Tallis: I was going to suggest 'cutting,' because they are only entitled to take off the cutting price, really.

Continuing, Mr. Tallis referred to the author's statement: 'So far as the author knows there is no case in South Wales where two separate colliery owners use one shaft which actually belongs to only one of them.' No doubt a good deal of money could be saved in that way, but the correct solution was amalgamation. He was afraid that to adopt the author's suggestion would lead to a great deal of trouble. As to the payment of royalties based upon the weight of the tram as it came to the pit top, mentioned by Mr. Ingledew, the general rule was to pay on the same weight as was paid to the collier. In the old days, when the collier filled fairly clean coal, there was not much in it; but things had altered in that respect, and washeries had been introduced. At the same time they could scarcely have one royalty for people who had washeries and another for those who had not got them. In his view the royalty should be paid on the coal that was marketed. The author said the lessee 'should not be compelled to pay the landlord a coal royalty on what is actually dirt, and there is little doubt that in the course of time this will be recognised by the royalty owner.' The author might have added 'and by the collier,' who was the person who was mainly responsible for dirty coal. He (Mr. Tallis) should like to endorse the remark of Mr. Ingledew that, 'speaking generally, the royalty owners of South Wales are keenly interested in the success of the great coal trade which, through their highly capable agents, they have assisted in building up; and there is a very widespread good feeling existing, as it ought to exist, between the

royalty owners on the one part and the colliery lessee on the other part.' He had very much pleasure in cordially endorsing these remarks. Mr. J. Fox Tallis.

The PRESIDENT said as Mr. Ingledew had to leave in a short time, he would take the opportunity on a future occasion to reply to the present and to the resumed discussion of his excellent Paper. The discussion would accordingly be adjourned, and meanwhile he would tender to the author the Institute's thanks for so ably bringing the subject of mining leases before them. (Applause.) The President.

The discussion was adjourned.

# NOTES ON A NEW TYPE OF COLLIERY TRAM.

By W. D. Woolley.

# NOTES ON A NEW TYPE OF COLLIERY TRAM.

By W. D. Woolley.

Since the issue of the Paper on Colliery Trams by Mr. J. Fox Tallis in the *Proceedings of the South Wales Institute of Engineers*, September 1900, the variation or development in colliery trams has not been very marked as far as general design is concerned, though in details such as buffers, door fastenings, hangers, and wheels numerous changes have taken place.

At the time of the issue of the above Paper the trams which were in use at the Tredegar Collieries were built of wood on a wooden frame and with fixed wheels. Shortly after this a tram with steel body and wood frame, more on the lines generally of that put forward by Mr. J. Fox Tallis, was introduced by Mr. A. S. Tallis into the collieries, and when Oakdale and Markham Collieries were first developed a tram of this type, which is shown in Fig. 1, was put into use.

The statement on p. 166 shows the principal dimensions of this tram (column 2) in comparison with the one suggested in Mr. J. Fox Tallis' Paper (column 1) and the new type now put forward (column 3).

The principal points of difference between No. 1 and No. 2 were that the frame of the new wood frame tram was oak instead of pitch pine, and Rowbotham wheels were used instead of fixed wheels. The door fastening was also of a

different type, namely, two small locking lugs in place of the drop bar.

This tram (No. 1) gave considerable satisfaction, and had only two weak points, namely: (1) that when the door was damaged it was difficult to prevent coal and dust escaping past the same (this applies in general to most trams of the swing door design); and (2) the wooden frames were a source

| | Mr. Fox Tallis' suggested Tram. | Wood Frame. Oakdale and Markham. | New Type Tram. |
|---|---|---|---|
| Length over all . . . | 6′ 3″ | 6′ 5″ | 6′ 5″ |
| Length of body (inside) . . | 5′ 7″ | 5′ 8″ | 5′ 8″ |
| Width of ,, ,, . . | 3′ 6″ | 3′ 7″ | 3′ 7½ |
| Depth of ,, ,, . . | 1′ 8″ | 1 8″ | 2′ 2′ |
| Height of rail . . . . | 3′ 0″ | 3′ 0½″ | 3′ 0⅝″ |
| Gauge . . . . . | 2′ 10″ | 2′ 10″ | 2′ 10″ |
| Tare . . . . . | 9 cwt. | 10cwt. 2q. 7lb. | 10 cwt. |
| Cubic capacity, without raising . | 33·5 | 33·5 | 39·27 |
| Carrying capacity . . . | — | 27 cwt. | 28·5 cwt. |

of trouble, especially in the smashes which are inseparable from underground haulage.

Further, with its angle-iron frame to the box and angle iron binders, it was, when built as a box tram, dust proof and complied with Section 62 (2) of the Coal Mines Act, 1911. With a door in bad condition this, however, could not be said. It was decided, therefore, to consider a new type, and as a result of certain experiments carried out at Markham Colliery by Mr. J. H. Austin, the manager, and Mr. E. Pearce, the colliery mechanic, a tram with angle-iron main frame. generally of the design shown in Fig. 2, was constructed.

The principal problem to be faced was the provision of a

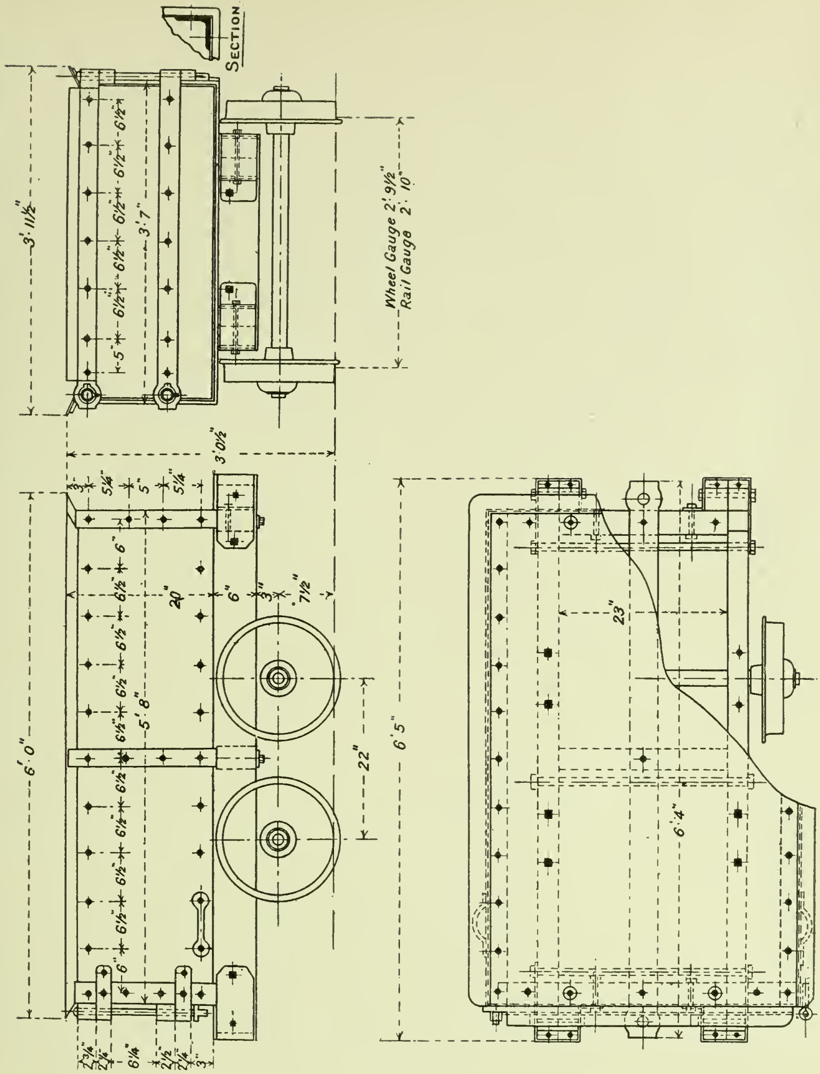



FIG. 1.

SPECIFICATION.

Back end binder, $2\frac{1}{2}'' \times 2\frac{1}{2}'' \times \frac{5}{16}''$ angle.
Middle binder, $2\frac{1}{2}'' \times \frac{1}{2}''$ flat.
Front binder, $3'' \times \frac{1}{2}''$ flat.
Top rails, sides, and ends, $2\frac{5}{8}'' \times 2\frac{5}{8}'' \times \frac{5}{16}''$ angle.
Door hinges, $2\frac{1}{2}'' \times \frac{1}{2}''$ flat.
Door hangers, $2\frac{1}{4}'' \times \frac{1}{2}''$ flat.
Door pin, 1″ round.
Draw bar, $4'' \times \frac{7}{8}''$ flat.
Staple for blocking, 1″ round.
Door catch, $2\frac{1}{2}'' \times \frac{1}{2}''$ flat.
Pedestal gland, $1\frac{1}{2}'' \times \frac{1}{4}''$ flat.
Pedestal bolts, $\frac{7}{8}''$ dia.
Frame bolts, $\frac{3}{4}''$ dia., 2′ 6″ long.
Buffer band, $1\frac{1}{4}'' \times \frac{1}{4}''$ flat.
Buffer band bolts, $\frac{1}{2}''$ diameter.
Rivets, $\frac{1}{2}''$ diameter.
Side plates, $5'\ 7\frac{3}{4}'' \times 1'\ 6'' \times \frac{1}{8}''$ thick.
Back end plate, $3'\ 6\frac{1}{2}'' \times 1'\ 6'' \times \frac{1}{8}''$ thick.
Door plate, $3'\ 6\frac{1}{2}'' \times 1'\ 6'' \times \frac{1}{8}''$ thick.
Bottom plate, $5'\ 7\frac{3}{4}'' \times 3'\ 6'' \times \frac{3}{16}''$ thick.
Buffer plate, $5\frac{1}{2}'' \times \frac{1}{8}''$ thick.
Pedestals, cast steel.
Wheels, 15″ diameter, loose.
Frame sills, $6'' \times 3'' \times 6'\ 4\frac{3}{4}''$.
Frame slots, $5\frac{1}{2}'' \times 3'' \times 23''$ without tenons.
Buffer blocks, $6'' \times 3'' \times 4''$ long.
Wheels and axles, Rowbotham type.

WEIGHT OF TRAM.

| | cwt. | qrs. | lbs. |
|---|---|---|---|
| Body, including bolts, rivets, &c. . . . . . | 6 | 2 | 7 |
| Wooden frame, oak . . | 0 | 3 | 23 |
| Wheels, axles, and brackets | 3 | 0 | 5 |
| Total weight of Tram . | 10 | 2 | 7 |

CUBIC CAPACITY.

| | cu. ft. |
|---|---|
| Without raising . . . | 33·5 |
| With raising 1′ above top of Tram | 45·9 |

CARRYING CAPACITY.

| | cwt. | qrs. | lbs. |
|---|---|---|---|
| Without raising . . | 20 | 0 | 0 |
| With 1′ 0″ of raising . | 27 | 0 | 0 |

door which would comply with Section 62 (2) and at the same time would provide reasonable facilities for unloading underground. In South Wales, with its big trams and the necessity of handling rubbish underground, these two points present great difficulty. A true dust-proof tram can only be a box tram or one with two closed ends. To run a Welsh colliery with only this type is impracticable, though a proportion may be used. To meet the dust difficulty it was necessary that when the tram was loaded the coal or rubbish should by its weight tend to close the door. With this in view an angle-iron end binder was put at the door end and the door made to lie on the inside of this (see Figs. 2 and 2A). In Fig. 2, with the door as originally designed, there is shown a rigid bar connecting the top of the sides of the tram at the door ends. On this the door slid by means of inverted U straps, and after it was raised a certain distance it could be turned flat to allow the unloader to get at the rubbish. This was not satisfactory, and the idea was given up.

The next type of door is Fig. 3; and of this type we have a very large number in use at Markham Colliery. In this the rigid bar was substituted by a hinged bar, which was fastened at the one end by a turning lug. In this type the door was raised vertically a certain distance, when the whole, including the bar, could be swung clear for unloading in the same manner as an ordinary door. The difficulty now was that, when the binder was strained and the sides spread, a good deal of trouble was experienced in closing the door, and occasionally the door would get displaced when the tram was being rotated in the Screens tumbler. To get over this the door was then tried as shown in Figs. 2A and 4. It was double-hinged and facilitated opening. The U slides, which were also the door stiffening plates, were done away with and made as an ordinary loose hinge strap, with the lug

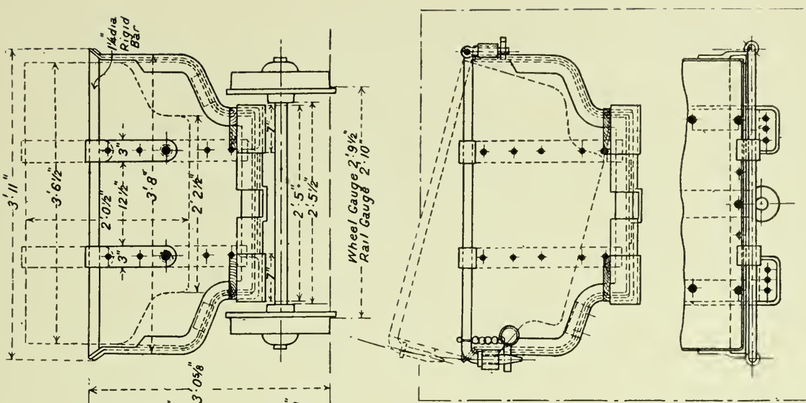



Fig. 2A.

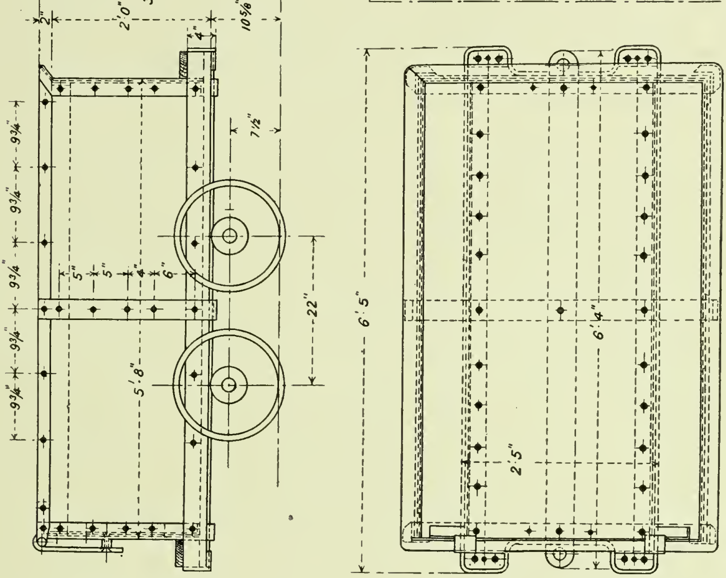


Fig. 2.

### Specification.

Bottom plate, 5′ 7$\frac{1}{4}$″ × 2′ 4″ × $\frac{3}{16}$″.
Side plates, 5′ 7$\frac{1}{4}$″ × 2′ 3$\frac{1}{2}$″ × $\frac{1}{8}$″.
End plates, 3′ 7$\frac{1}{4}$″ × 1′ 11″ × $\frac{3}{16}$″.
Main angles for frame, 3$\frac{1}{2}$″ × 3$\frac{1}{2}$″ × $\frac{1}{2}$″ angle.
Hitching plate, 4″ × $\frac{7}{8}$″ flat.
Middle binder, 3″ × $\frac{1}{2}$″ flat.
A1 end binders, 2$\frac{1}{2}$″ × 2$\frac{1}{2}$″ × $\frac{3}{8}$″ angle.
Straps for door hinges, 3″ × $\frac{1}{2}$″ flat.
Cross bar for door, 3″ × $\frac{1}{2}$″ flat.
End bar for door, 1$\frac{1}{4}$″ diameter, round.
Straps for hitching plate, 2″ × $\frac{3}{8}$″ flat.
Splay angles for sides, 2$\frac{3}{4}$″ × 2$\frac{3}{4}$″ × $\frac{5}{16}$″ angle.
Splay angles for ends, 2$\frac{3}{4}$″ × 2$\frac{3}{4}$″ × $\frac{5}{16}$″ angle.
Hangers, steel.
Wheels, 15″ diameter.
Rivets : sides and ends, $\frac{1}{2}$″ diameter.
Rivets : hangers and hitching plate, $\frac{3}{4}$″ diameter.
Wheels and axles, Rowbotham type.

### Weight of Tram.

| | cwt. | qrs. | lbs. |
|---|---|---|---|
| Body, including bolts, rivets, and frame | 6 | 3 | 23 |
| Wheels, axles, and brackets | 3 | 0 | 5 |
| Total weight of Tram | 10 | 0 | 0 |

### Cubic Capacity.

| | cu. ft. |
|---|---|
| Without raising | 39·27 |
| With raising 1′ 0″ above top of Tram | 51·50 |

### Carrying Capacity.

| | cwt. | qrs. | lbs. |
|---|---|---|---|
| Without raising | 21 | 0 | 0 |
| With 1′ 0″ of raising | 28 | 2 | 0 |

on end of bar replaced by a 'pin point,' as shown; this is much more easy to close, even if the tram is strained.

This further development (Figs. 2A and 4) has so far been satisfactory, but it is not yet perfect, and a number of other ideas have been tried; but unless they fit or slide on the inside of the angle-iron binder, then the whole object of this binder is defeated. As a doorless tram this type is very satisfactory, especially when the ends are made, as we are now doing, by pressing the same out of one plate and riveting it to the side plates and dispensing with angle-iron end binders.

The whole difficulty that has to be faced arises out of the door, it being often found that the collier will not properly close the same even in this type, as in almost all others, before filling the tram, and though there is a tendency of the coal that is put into the tram to close the door, it will occasionally arise that even this door is not properly closed and dust-tight. On the other hand, if the ordinary swing or outside hinge door is not properly fastened it is a danger on the haulage road and whilst going up the shaft, whilst this new type of door, even if not quite properly closed, is rarely a source of danger of this kind.

A number of ideas as to doors have been put forward, but nearly all are too complicated to be satisfactory, as all parts of a tram require to be as simple and strong as possible.

The writer prefers a tram with splay angle around the top of the sides, as being a much stronger and more satisfactory job. As far as cost of repairs is concerned, the tram compares favourably with the old type with frame, but it has one disadvantage, namely, that when the tram has a severe bump and the main angle-iron which forms the buffer also gets damaged, then the whole tram has to be cut up and rebuilt. In the case of an underframe tram it often happens that the

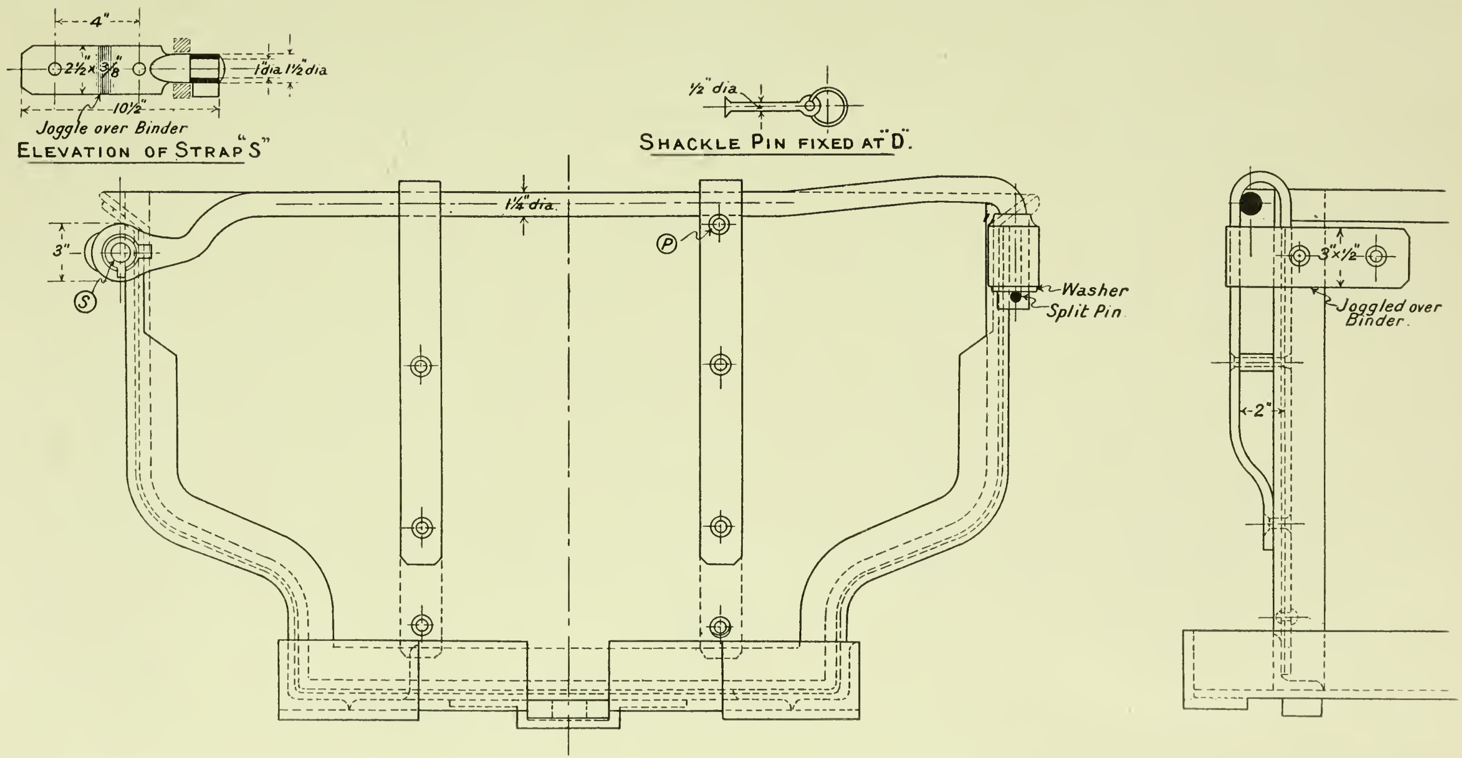

4"
2½" x ⅜"
1" dia
1½" dia
10½"
Joggle over Binder
Elevation of Strap "S"
½" dia
Shackle Pin fixed at "D".
1¼" dia.
3"
S
P
Washer
Split Pin
3" x ½"
Joggled over Binder.
2"

Fig. 3.

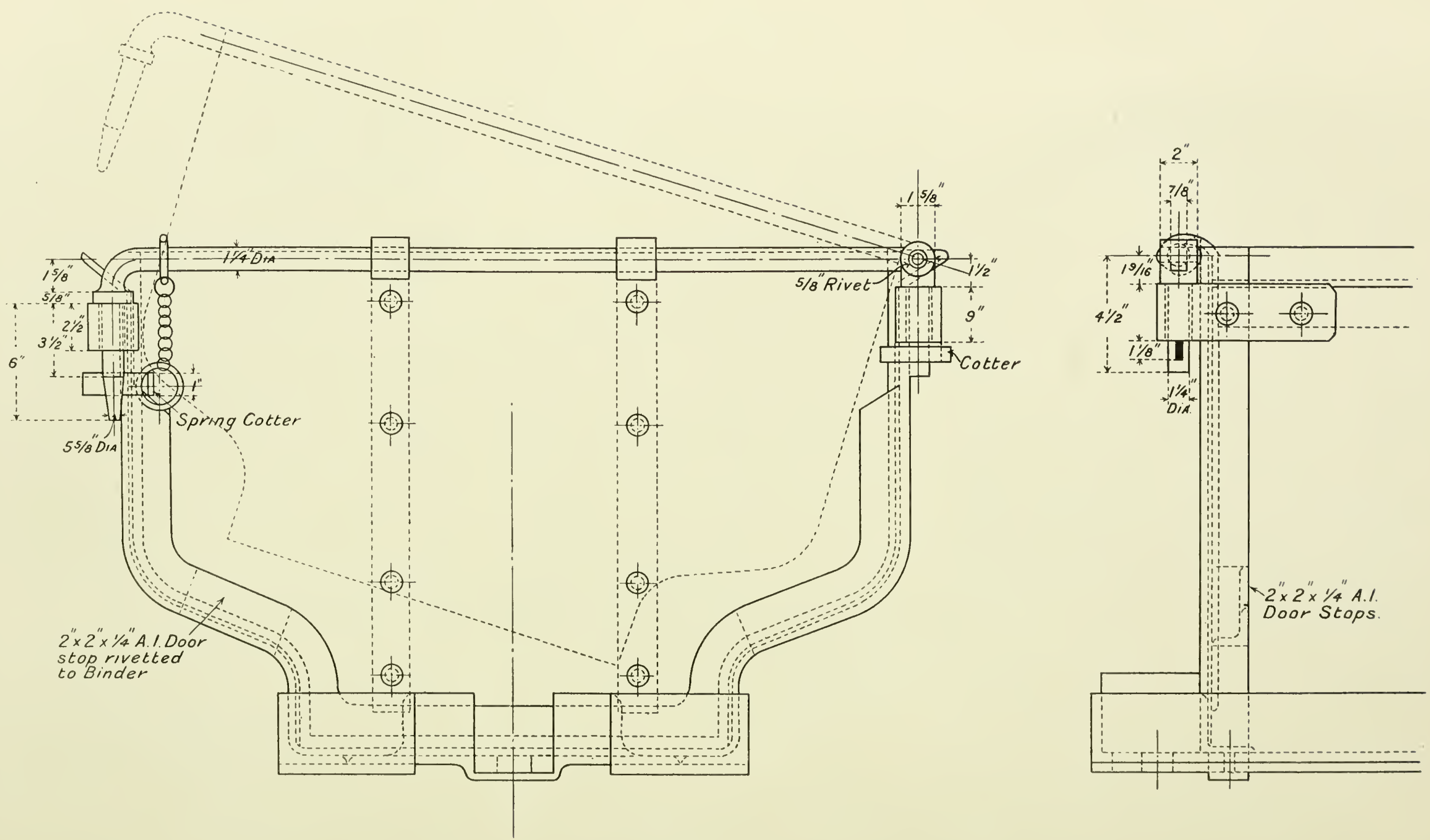

1¼" DIA
1⅝"
⅝"
2½"
3½"
6"
1"
Spring Cotter
5⅝" DIA
2" x 2" x ¼" A.I. Door stop rivetted to Binder
1⅝"
1½"
⅝" Rivet
9"
Cotter
2"
⅞"
1 9/16"
4½"
1⅛"
1¼" DIA.
2" x 2" x ¼" A.I. Door Stops.

FIG. 4.

frame itself takes the whole of the shock, and the box can be taken off and put on a new frame and the old one repaired.

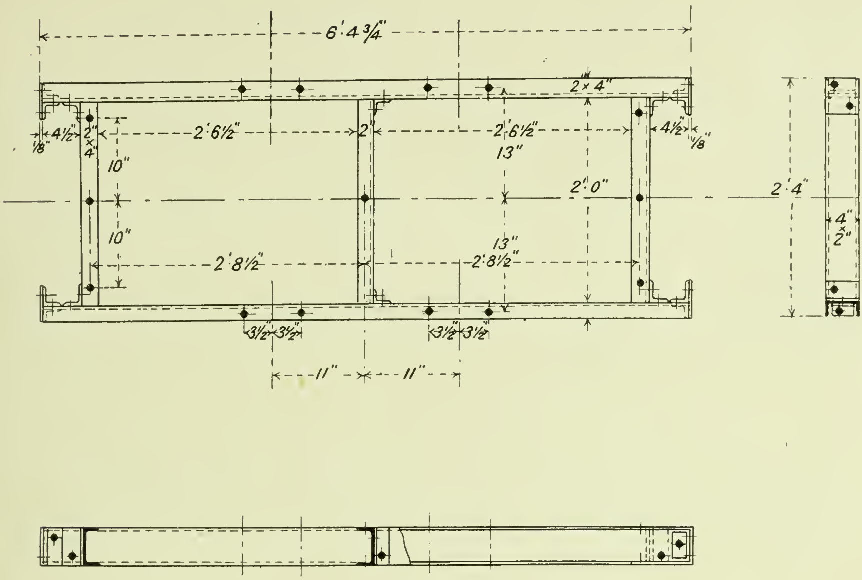



Fig. 5.

Specification.

| Total No. or Length. | Size. | Description. | Unit Weight, lbs. per foot. | Total Weight, lbs. |
|---|---|---|---|---|
| 18′ 8″ | 4″ × 2″ | Channels . . . . | 7·96 | 148·5 |
| 2′ 8″ | $2\frac{1}{4}''\times 2\frac{1}{4}''\times \frac{1}{4}''$ | Angles . . . . . | 3·61 | 9·5 |
| 2′ 0″ | $1\frac{3}{4}''\times 1\frac{3}{4}''\times \frac{5}{16}''$ | Angles . . . . . | 3·39 | 6·75 |
| 1′ 3″ | $3\frac{3}{4}''\times 4''\times \frac{3}{8}''$ | Flat . . . . . | 5·00 | 6·25 |
| 24 | $\frac{5}{8}''$ | Rivets . . . . . | — | — |
| | | Total weight of frame . . | | 171 lbs. |

All holes in frame (shown thus -●-) for $\frac{7}{8}''$ diameter bolts.

Further, the square box tram has certain advantages of design as regards manufacture, repairs, and handling, and we are at present experimenting with steel frames in the place of the original wooden type (sketches are shown in Fig. 5),

of which a number are at present in use. Fig. 6 shows the type proposed to be adopted to overcome one or two

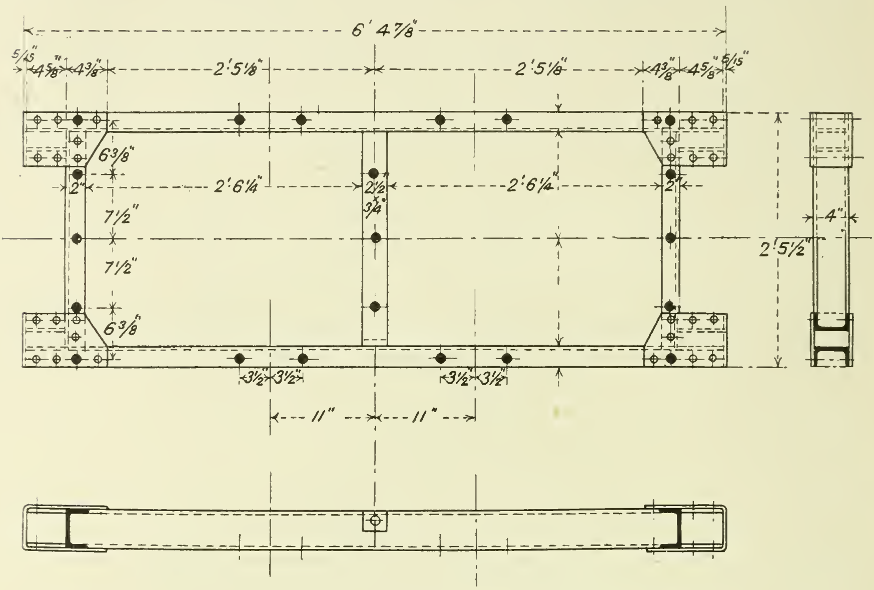



Fig. 6.

Specification.

| Description. | Total No. | Size. | Length. | Channel at 8 lbs. per foot. | Channel at $6\frac{1}{2}$ lbs. per foot. |
|---|---|---|---|---|---|
| Side channels . . | 2 | 4″ × 2″ | 6′ $4\frac{1}{4}$″ | 102 lbs. | $82\frac{1}{2}$ lbs. |
| End channels . . | 2 | 4″ × 2″ | 2′ $1\frac{1}{2}$″ | 34 ,, | 28 ,, |
| Buffer channels . | 4 | 4″ × 2″ | $4\frac{5}{8}$″ | 12 ,, | 10 ,, |
| Middle stretcher . | 1 | $2\frac{1}{2}$″ × $\frac{3}{4}$″ | 2′ $5\frac{1}{2}$″ | $15\frac{1}{2}$ ,, | $15\frac{1}{2}$ ,, |
| Buffer plates . | 4 | 6″ × $\frac{5}{16}$″ | 1′ 10″ | $44\frac{3}{4}$ ,, | $44\frac{3}{4}$ ,, |
| Rivets . . . | 30 | $\frac{5}{8}$″ diam. | | | |
| | | Total weight of frame . . | | $208\frac{1}{4}$ lbs. | $180\frac{3}{4}$ lbs. |

$\frac{3}{4}$″ diam. bolt holes for securing body to frame shown thus ●
,, ,, ,, hangers and hitching plate ◍

defects of the type shown in Fig. 5. The only disadvantage with these frames is that it makes the tram heavier. The original wood frame is shown in Fig. 7. For conveyor work the height of the tram of either type will be increased.

This tram and door are not put forward as perfect, but rather with the object of inviting criticism, and therefrom possibly obtaining ideas that may be helpful to all concerned.

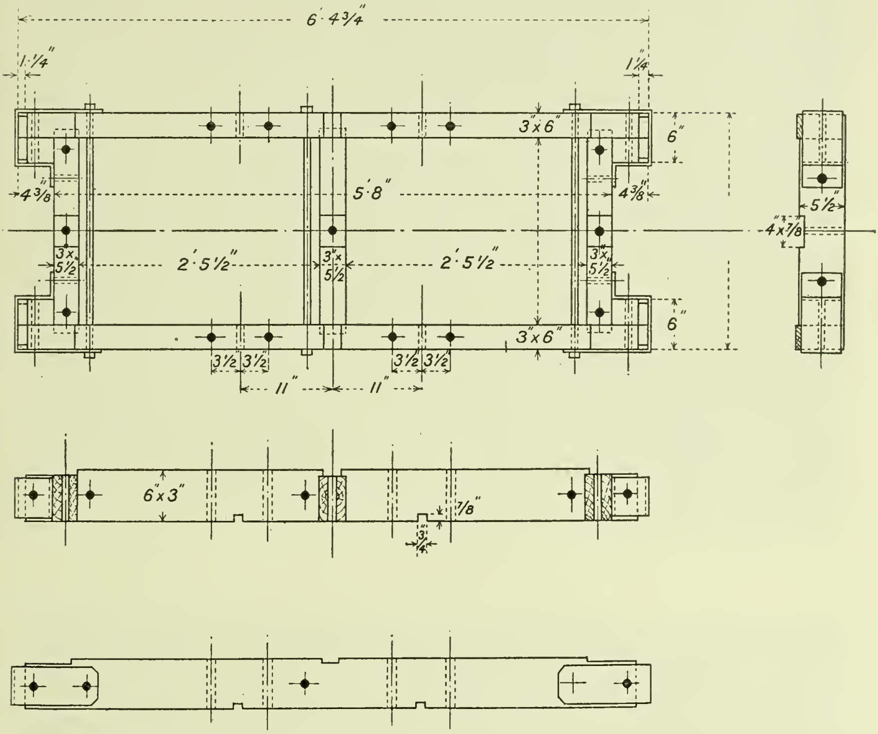


Fig. 7.

SPECIFICATION.

| Description. | No. | Size. | Material. |
|---|---|---|---|
| Side sloats . . | 2 | $6'' \times 3''$ | oak |
| Cross sloats . . | 3 | $5\frac{1}{2}'' \times 3''$ | ,, |
| Tie bolts . . | 3 | $\frac{3}{4}''$ diam. | wrought iron |
| Buffer bands . . | 4 | $1\frac{1}{4}'' \times \frac{1}{4}''$ | ,, |
| Buffer plates . . | 4 | $5\frac{1}{2}'' \times \frac{1}{8}''$ | ,, |

Total weight, 109 lbs.

Three photographs are also given, showing (Fig. 8) a view of the trams in use underground and (Figs. 9 and 10) general views of the tram.

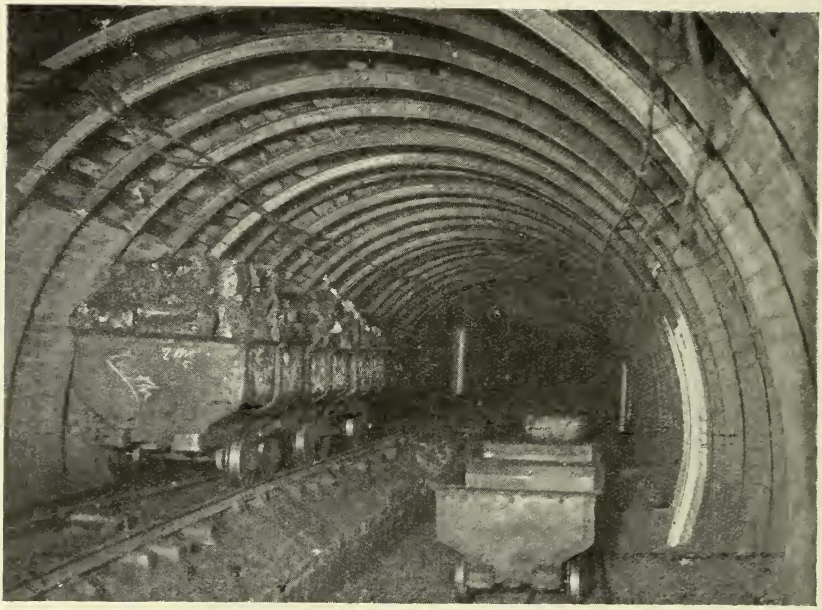


Fig. 8.

Fig. 9.

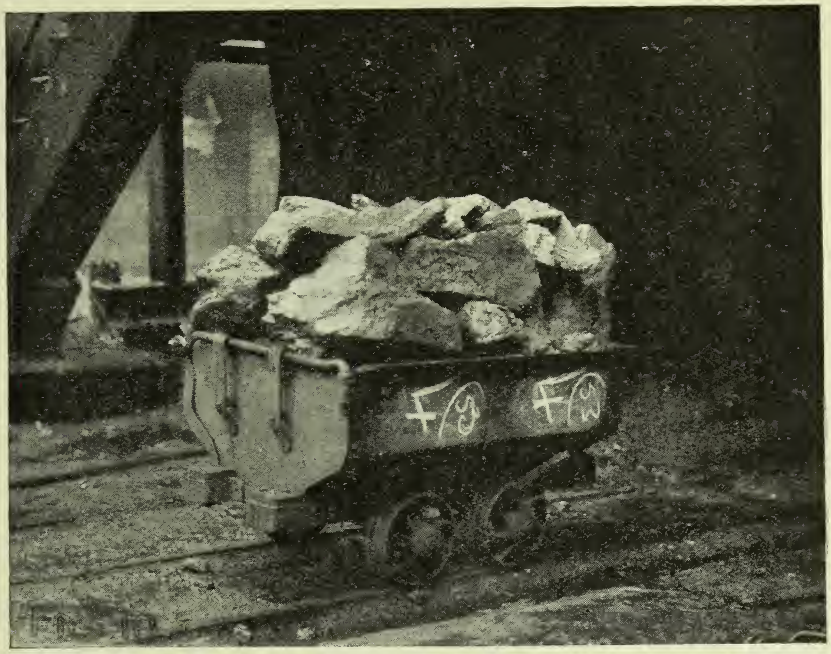


Fig. 10.

Mr. David Hannah said the subject of Mr. Woolley's paper was highly important to every colliery manager, and in view of the short time which members of the Institute had had to study the details of this type of tram, he hoped the discussion would be adjourned to the next meeting. **Mr. David Hannah.**

Mr. Greenland Davies said the great thing to accomplish in the designing of colliery trams was that they should be dust tight (according to Act of Parliament) at the sides, the bottom, and the ends. He should like Mr. Woolley to tell them, when replying on the future discussion, how his tram behaved in those respects. **Mr. Greenland Davies.**

The President adjourned the discussion of the Paper, and proposed a vote of thanks to the author. **The President.**

The proceedings closed.

# PROCEEDINGS.

## Summer Meeting at the Conishead Priory, Tuesday, June 8, 1920.

In connection with the visit to Furness and the Lake District of the South Wales Institute of Engineers, a Special General Meeting of Members was held at Conishead Priory, near Ulverston, on Tuesday, June 8, 1920. The President (Mr. J. Dyer Lewis) occupied the chair.

The President. In opening the meeting, the President said they had met together that evening under excellent conditions and surroundings. He hoped they might have had a few ladies to attend their meeting, as they sometimes had on the occasion of their summer outings, but he supposed the beauties of Holker Hall had kept them away; perhaps some of them might get back in time to take part in their deliberations. They had in the country just now very clever lady chemists. but whether they had a lady in their company who could throw light on the highly technical subject they had met to consider that evening he did not know. He was very sorry Dr. Wheeler was not with them. Dr. Wheeler had been looking forward to that meeting, and had expressed his very great regret he was unable to be with them, as unfortunately he had to attend at the Home Office. The paper which Mr. Tideswell, who was a research chemist in connection with the Home Office experiments at Eskmeals, proposed to read to them was on

'The Constitution of Coal in relation to its Spontaneous Combustion.' It was a subject which had come to the front a good deal of late, although it had been before the mining world for many years. Down in South Wales they had not many coal seams liable to spontaneous combustion. There were a few in the west—some two or three. In England, however, there were many seams liable to spontaneous combustion underground. As practical men they had always laid the cause at the feet of the little substance called pyrites. He thought the chemists had now thrown the subject of pyrites overboard almost entirely and put it down to oxidation. As he had said, they had two or three seams in the west of Wales which were very liable to spontaneous combustion. In one of them, situate near Neath, many years ago they were accustomed to have from fifteen to twenty-five cases of spontaneous combustion in one year. That number had been greatly reduced of late years, and he was satisfied it was because greater attention was devoted to the filling up of old places, which was one of the preventatives of spontaneous combustion. In such cases the coal was generally soft, and a fall of roof on a heap of coal rendered it more liable to spontaneous combustion. He did not intend to occupy more of their time, for they were waiting for their dinner, but he would ask Mr. Tideswell to give them a part, at any rate, of his very valuable paper. **The President.**

Mr. TIDESWELL then read his paper on 'The Constitution of Coal in relation to its Spontaneous Combustion.' **Mr. Tideswell.**

# THE CONSTITUTION OF COAL IN RELATION TO ITS SPONTANEOUS COMBUSTION.

By F. V. Tideswell, M.Sc.

# THE CONSTITUTION OF COAL IN RELATION TO ITS SPONTANEOUS COMBUSTION.

By F. V. Tideswell, M.Sc.

Before considering the question of the influence of the composition of a coal on its liability to ignite spontaneously, it is necessary to discuss briefly the views that have been held regarding the factors involved in that phenomenon. To the proper understanding of these views, which vary so considerably between one worker and another, it is perhaps desirable to present a rather detailed account of the many researches undertaken into the subject. Such an account illustrates well the difficulties contended with and the conflicting data obtained, which makes progress towards an understanding of the precise nature of the spontaneous combustion of coal and a solution of the problem of its prevention so slow and doubtful.

The following is a summary of the more important work carried out to date on the subject of the spontaneous combustion of coal.

## *Historical.*

The question of the deterioration and spontaneous combustion of coal whilst on storage, conveyance, and, more important, whilst down the pit, has received serious attention from investigators for considerably over half a century. The

earliest workers on the subject attributed the absorption of oxygen and consequent heating-up of the coal solely to its contents of pyrites, and little real progress towards the true understanding of the problem was made until E. Richter showed that the coal substance itself was capable of oxidation at a rate at least comparable with that of pyrites.

E. Richter (1868, 1869, 1870) established that the main features of the reaction between coal and oxygen are:

(1) That coal even at ordinary temperatures absorbs oxygen, one portion of which enters into combination with the coal substance, increasing its weight; the other portion forms carbon dioxide and water in larger or smaller quantities. With some coals no carbon dioxide appears to be evolved.

(2) The absorption of oxygen is continuous; though the high initial rate quickly slows down, yet absorption never entirely ceases.

(3) This oxidation is accompanied by the production of heat, and

(4) is promoted by increased temperature.

The main fact that coal can ignite 'spontaneously' is readily explained by these observations.

Richter drew a parallel between the absorption of moisture by a coal and its absorption of oxygen, and suggested that the first stage of the latter process is purely physical. The diminution with time of the absorptive power of coal for oxygen was shown, however, not to be due to the condensation of evolved carbon dioxide in the coal, as had been suggested by Varrentrapp (1865).

Richter's observations led him to conclude that the absorption of oxygen is caused mainly by the presence in coal of disposable hydrogen. During the absorption of oxygen,

whether at atmospheric or at higher temperatures, the content of disposable hydrogen is diminished, while at the same time certain of the more easily oxidisable portions of the carbon contribute to the oxygen absorption. The absorption ceases when the hydrogen and oxygen content of the coals are in the same ratio as in water. With regard to the effect of pyrites and of moisture, Richter concluded:

(1) That pyrites is quite unnecessary to explain the heating of coal, and appears to have no effect on this heating.
(2) That moisture appears to exert a slightly deterrent action on the oxidation of coal, unless in the presence of a large proportion of pyrites.

Although some of the minor points of Richter's work, such as the parts played by pyrites and by moisture, have since been challenged, his main conclusions have stood to the present day and have formed the basis of most subsequent investigations.

The next important work on the subject was that of Fayol (1879), who followed on and extended Richter's work, reaching the same general conclusions—that the ignition of coal was due to the oxidation by the air of the organic constituents of the coal, with consequent heating, the extent of which is dependent on the physical conditions obtaining. The great importance of these physical conditions in determining the extent of heating and the actual ignition of the coal was emphasised by Fayol. Contrary to the general belief then held, no appreciable increase was found in the liability of a coal to inflame as a result of wet weather.

Most of Fayol's work was in connexion with the safe storage of coal on a large scale, and it is not necessary to treat it more fully here. This applies also to the Reports of the New South Wales Commissions on the spontaneous combustion of coal

during shipment. A full account of both researches is given by Threlfall (1909).

Mahler (1892) confirmed the result obtained by both Richter and Fayol—that exposure to the air increases the weight and the oxygen content of a coal ; he found also that the yield of volatile matter is increased, whilst the temperature at which destructive distillation begins is much lowered. Mahler's most important observation was that there is a formation of humic acids (ulmins) during the course of the oxidation. He connected the presence of these bodies with the loss of coking power of the coal which occurs as a result of weathering, by assuming the presence in coal of carbohydrates essential for the formation of the binding material of the coke, these carbohydrates being changed to the ulmins by oxidation.

Fischer (1899) investigated the changes and products of the action of air on coal and the effect of moisture, but with inconclusive results. He found that fresh coal absorbs bromine to a considerable extent, taking up as much as one-half of its weight ; whilst after oxidation, absorption of bromine occurs only to a slight extent. Fischer concluded that coal contains larger or smaller quantities of unsaturated compounds which absorb oxygen rapidly, gaining in weight. A second class of compounds combine with oxygen, evolving water and carbon dioxide. He considered the first class of compounds to be mainly responsible for the heating of coal, and suggested as a practical test that one gramme of the powdered coal should be shaken with twenty c.c. of semi-normal bromine solution during five minutes. If any free bromine remained, the coal could be safely stored.

Some years later a contribution on ulmins with special reference to their reaction with ozone was made by Erdmann and Stolzenberg (1908), who agreed with Fischer's assumption that it is the unsaturated constituents of brown coal, in par-

ticular the ulmins ('huminsauren'), which are the cause of spontaneous combustion. The ulmins, which were obtained by the extraction of the brown coal with an aqueous solution of sodium hydroxide, with subsequent acidification and filtration, were shown to be unsaturated compounds, since they attack bromine without evolving hydrogen bromide. Further, the ulmins react vigorously with ozone. A current of oxygen containing 2 per cent. of ozone, passed over the ulmins at a rate of 500 c.c. per minute, caused combustion in 23 minutes. Briquetted brown coal coarsely powdered and moistened took fire in 70 minutes under these conditions; whilst when it was air-dried to a moisture content of 9·8 per cent. the temperature did not rise above 48° C. These experiments led the authors to the conclusion that the self-ignition of small coal is due entirely to the action of ozone. Pyrites was found to retard the action of ozone when added to pure ulmin, while alone, little action occurred even when the pyrites was moistened.

In amplification of their theory, Erdmann and Stolzenberg suggested that the self-ignition of a coal is probably not determined by the ozone content of the air, but rather by the production of ozone due to the evaporation of moisture from the surface of the coal. This they considered would explain why coal in heaps catches fire so frequently on warm sunny days after rain. The ozone thus formed immediately reacts with, and is absorbed by, the ulmins, which break up by its action, in the presence of water, into carbon dioxide and saturated decomposition products. Under suitable conditions, the heat generated by the action of ozone accumulates, increasing the temperature of the coal until the less active atmospheric oxygen begins to react. Substances other than coal react with ozonised air. Thus, when treated with air having an ozone content of 2 per cent., cotton waste soaked in

linseed oil ignites quickly. Under similar treatment moist cellulose (filter paper) shows no rise in temperature.

The production of ozone and its possible influence on the ignition of coal has been suggested by others, for example Whalley (*see* discussion on Winmill, 1913). Possibly also the well-known action of coal on a photographic plate (*see* Russell, 1908) can be explained in part as occurring through the agency of ozone.

A series of papers by Boudouard (1908; 1909 A; 1909 B; 1911) deals with the weathering of coal and its connexion with the loss of coking power and the formation of ulmins. Boudouard described the brown acidic products formed on the oxidation of coal, and confirmed Mahler's (1892) observation that the formation of ulmins accompanied the disappearance of the coking power of a coal. With Mahler, Boudouard considered that the coking power is due to products of cellulosic origin, complex condensation products of carbohydrates; the ulmins found in non-coking coals being the result of oxidation of these products. Boudouard obtained but slight confirmation of this suggestion on extracting a coal successively with potassium hydroxide, hydrochloric acid, and Schweizer reagent. On acidification of the last extract a grey flocculent mass was obtained, similar to cellulose but not definitely identifiable therewith.

In his later publications Boudouard gave details of anomalous results obtained with lignites. Whilst the ulmin content of wood, peat, and bituminous coal increases when they are oxidised at 110° C., that of lignite decreases. Further oxidation at 150° C. to 170° C. increases the ulmin content of all four substances. Contrasting these results with the absence of ulmins in anthracites and coals of a low content of volatile matter, whether natural or oxidised, Boudouard concluded that the ulmins are formed by a breakdown of the plant struc-

tures, and represent an intermediate step in the formation of coal; that they condense to form more highly carbonised types, with a loss of their acidic character; and, finally, through the action of temperature and pressure, are transformed into coals and anthracites. Lignites he regarded as being formed by a different process.

A further contribution to the subject was made by Mahler (1913). Mahler agreed with Dennstedt and Bunz (*q.v.*) regarding the greater amount of water retained by a coal after oxidation (though this is not completely borne out by the data recorded), and suggested that this water was present as a hydrate easily decomposed by heat. Mahler's statement in this connexion that 120° C. appears to be a critical temperature of oxidation, judged by the products formed, must in the absence of confirmation be accepted with reserve. He found that the amount of carbon dioxide, carbon monoxide, and water yielded by a coal on oxidation above 125° C. is much greater than at slightly lower temperatures; also that oxidation at 80° C. gives rise to very little ulmin, whilst at 125° C. much ulmin is obtained, corresponding with the large disengagement of water previously mentioned as taking place at that temperature. Mahler also gives some interesting data with regard to the liquid products of oxidation.

Going back a few years to a time slightly prior to Boudouard's first publication, Dennstedt and Bunz (1908) had tested a large variety of coals in an endeavour to determine the connexion between the liability of a given coal to spontaneous combustion and one or other of the factors entering into its composition. They determined the comparative tendencies of the coals to self-heat by heating them in a current of dry oxygen at 135° C. or 150° C. When making a test, the sample, sieved through a mesh of 144 per square cm., was placed in a brass tube, heated in an oil bath at the desired

temperature, and dried by a current of carbon dioxide preheated to the temperature of the oil bath. When the coal-temperature reached 100° C. to 115° C. the carbon dioxide was replaced by oxygen, which was delivered at a rate of between two and three litres per hour. The temperature of the coal was read at intervals of two or three hours, and if it became higher than that of the bath, the speed of the current of oxygen was increased.

From their behaviour under this test coals were divided by Dennstedt and Bunz into four classes, in order of their ease of ignition :

(1) Those in which the temperature of the coal did not exceed that of the oil bath.

(2) Those which showed a marked increase of temperature, and in some instances ignited, if the coal was first heated to 135° C. for two hours and its temperature then raised to 150° C.

(3) Those which at first showed only a slight rise in temperature, either at 135° C. or 150° C., but could be caused to heat or ignite by increasing the current of oxygen.

(4) Those which heated rapidly either at 135° C. or 150° C. and ignited during the first or second hour. Such coals were considered to be very liable to spontaneous combustion.

Dennstedt and Bunz concluded from their experiments that neither the mineral constituents (*e.g.* pyrites) nor the organic sulphur and nitrogen in a coal have any influence on its spontaneous combustion. On the other hand, a relation was traced between the liability to ignite and (1) the friability and (2) the moisture content of the coals. There also seemed to be a relationship between the proportions of the coal extractable by organic solvents and its ease of oxidation. In general,

the percentage extractable by pyridine was much less after than before treatment with oxygen. From the figures quoted below it will be seen that this can scarcely be said to hold with coals containing a small percentage only of extractable matter. These coals, however, show discrepancies in other respects.

The 'oxidised' coals referred to in Table I. were obtained by heating the finely powdered coals in an open vessel during one day at 130° C. and nine days at 140° C. to 150° C.

The 'Iodine Numbers' were obtained by treating 1 gramme of the coal with 25–50 c.c. of alcoholic HgI.HgCl solution for twenty-four hours. The volume was made up to 100 c.c. with 10 per cent. KI, and 50 c.c. taken and titrated. The value varied with the fineness of the dust.

Dennstedt and Bunz drew the conclusion that coal consists of two very dissimilar portions. The first resembles the montan wax existing in brown coals, and is the part soluble in organic solvents. Though it contains more oxygen than montan wax, probably both have a similar origin. The second portion of the coal, insoluble in solvents, is derived from the celluloses of the original wood from which the coal was formed. This part contains the unsaturated portions of the coal, and it is these which are responsible for the self-heating. On oxidation this insoluble portion forms ulmin compounds as the final product of their slow oxidation. The more readily inflammable coals contain more oxygen and little or no disposable hydrogen (*cf.* Richter); a certain degree of original oxidation of the coal is necessary to render possible further rapid atmospheric oxidation, leading to spontaneous ignition. This explains why the presence of the ulmins is intimately connected with the tendency of a coal to ignite—why they are present in large quantities in the more readily inflammable coals. Dennstedt and Bunz also considered that the presence of ulmins accounted for the hygroscopic nature of such coals.

TABLE I.

| Coal. | Nixon Navigation. | | Germania. | | Durham. | | Bunkerkohle. | | Merrys. | | Schottische. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Original. | Oxidised. | Original. | Oxidised. | Original. | Oxidised. | Original. | Oxidised. | Original. | Oxidised. | Original. | Oxidised. |
| Water ($H_2$ stream at 105°) | 1·01 | — | 1·13 | — | 3·17 | — | 2·45 | — | 8·10 | — | 8·65 | — |
| Analysis, dry coal : | | | | | | | | | | | | |
| Pyrites | 0·18 | 0·07 | 0·20 | 0·19 | 1·70 | 0·95 | 0·08 | 0·12 | 0·12 | 0·21 | 0·46 | 0·14 |
| Sulphates | 0·12 | 0·10 | 0·07 | 0·15 | 0·70 | 1·50 | 0·28 | 0·38 | 0·14 | 0·58 | 0·31 | 0·48 |
| Other mineral | 3·15 | 4·43 | 4·43 | 2·61 | 9·84 | 9·38 | 4·01 | 3·88 | 5·94 | 6·43 | 6·52 | 5·16 |
| Total mineral | 3·45 | 4·60 | 4·70 | 2·95 | 12·24 | 11·83 | 4·37 | 4·38 | 6·20 | 7·22 | 7·29 | 5·78 |
| H. | 4·59 | 3·54 | 4·36 | 3·57 | 4·65 | 2·93 | 5·25 | 3·45 | 4·03 | 2·81 | 4·53 | 3·19 |
| C. | 86·19 | 81·81 | 85·75 | 77·63 | 74·18 | 63·88 | 80·69 | 70·38 | 75·77 | 66·54 | 76·85 | 67·07 |
| Organic S. | 0·90 | 1·01 | 1·16 | 1·12 | 2·96 | 1·18 | 1·72 | 0·98 | 1·20 | 0·76 | 0·99 | 1·05 |
| N. | 0·85 | 0·84 | 1·42 | 1·19 | 1·41 | 1·19 | 1·65 | 1·71 | 1·64 | 1·26 | 1·46 | 1·68 |
| O. | 4·02 | 8·20 | 2·61 | 13·54 | 4·56 | 18·99 | 6·32 | 19·10 | 11·16 | 21·41 | 8·88 | 21·23 |
| | 100·0 | 104·0 | 100·0 | 108·8 | 100·0 | 109·1 | 100·0 | 107·9 | 100·0 | 105·9 | 100·0 | 107·7 |
| Analysis, ash-water-free coal : | | | | | | | | | | | | |
| H. | 4·76 | 3·86 | 4·58 | 4·00 | 5·30 | 3·62 | 5·4 | 3·90 | 4·30 | 3·35 | 4·89 | 3·65 |
| C. | 89·27 | 89·19 | 89·98 | 87·03 | 84·53 | 79·04 | 84·38 | 79·41 | 80·78 | 75·95 | 82·89 | 76·66 |
| S. | 1·01 | 1·08 | 1·22 | 1·32 | 3·37 | 1·46 | 1·80 | 1·12 | 1·28 | 0·87 | 1·07 | 1·20 |
| N. | 0·88 | 0·90 | 1·60 | 1·28 | 1·61 | 1·47 | 1·73 | 1·93 | 1·75 | 1·40 | 1·57 | 1·92 |
| O. | 4·08 | 8·97 | 2·62 | 15·17 | 5·19 | 23·51 | 6·62 | 21·54 | 11·89 | 24·29 | 9·58 | 24·27 |
| Effect of oxidation : | | | | | | | | | | | | |
| — H. | 0·90 | | 0·58 | | 1·68 | | 1·57 | | 0·95 | | 1·24 | |
| — C. | 0·08 | | 2·95 | | 5·49 | | 4·97 | | 4·83 | | 6·23 | |
| + O. | 4·89 | | 12·55 | | 18·32 | | 14·92 | | 12·40 | | 14·69 | |
| Vol. matter per cent. | 12·03 | 13·92 | 21·92 | 23·24 | 29·98 | 36·02 | 35·35 | 34·28 | 32·37 | 38·37 | 30·46 | 35·11 |
| Iodine No. | 15·03 | 5·61 | 10·57 | 20·56 | 35·06 | 18·07 | 24·49 | 14·96 | 51·73 | 19·63 | 59·24 | 22·43 |
| Humus No. | — | 0·3 | — | 2·4 | — | 11 | — | 21 | — | 30 | — | 36 |
| Pyridine extract per cent. | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

As indications of the liability of a coal to self-ignition, Dennstedt and Bunz recommend, in addition to the oxidation test, the Maumené test (measurement of the heat developed on addition of concentrated sulphuric acid) and the iodine value. A high absorption of iodine means a large proportion of the unsaturated compounds responsible for ignition. The conclusions reached are rather sweeping, and are not supported completely by the evidence put forward.

In 1915 a controversial paper by Nübling and Wanner (1915) appeared. The conclusions drawn by these authors were markedly different from those of Dennstedt and Bunz. Using an apparatus slightly modified from that of the last-named authors, Nübling and Wanner determined the ignition-temperatures of several coals, before and after extraction with various solvents. From the results obtained with a Ruhr coal they concluded that the portion of a coal soluble in organic solvents is responsible for the spontaneous inflammation of coal; thus:

| Ruhr Coal. | Original. | Residue after Extraction with | | | | |
|---|---|---|---|---|---|---|
| | | Ether. | Acetic Acid. | Acetone. | Quinoline. | Pyridine. |
| Ignition-temperature . | 150° C. | 159° C. | 165° C. | 170° C. | 170° C. | 187° C. |

A series of experiments was then made, using pyridine as solvent, with three different coals: (1) Westphalian coal, known to be liable to spontaneous ignition; (2) a still more inflammable Yorkshire coal, and (3) a Saar coal, which had been weathered during long storage.

The pyridine extraction was carried out in the cold. The extract was precipitated with ether and washed well with

ether, as was the residue. The extract was then dried at 80° C. *in vacuo.* The extract contained but little nitrogen and sulphur.

Bromine absorptions of the various fractions of the coals were also made by agitating 5 grammes of coal with 10 c.c. of chloroform and adding standard bromine drop by drop until free bromine remained, as indicated by the formation of a yellow edge on narrow strips of filter paper immersed in the solution.

TABLE II.

| Class of Coal. | West-phalian. | Yorkshire. | Saar (Heinitz). |
|---|---|---|---|
| | Per Cent. | Per Cent. | Per Cent. |
| Ash in coal | 12·06 | 4·18 | 4·61 |
| Analysis of ash free coal : | | | |
| Carbon | 80·62 | 79·45 | 82·10 |
| Hydrogen | 4·87 | 5·30 | 5·39 |
| Cold pyridine extract | 6·50 | 9·40 | 5·82 |
| containing Carbon | 81·40 | 79·75 | 79·14 |
| containing Hydrogen | 5·96 | 6·06 | 6·29 |
| Temperature of ignition in stream of oxygen of : | ° C. | ° C. | ° C. |
| 20 grms. of coal | 152 | 138 | 165–182 |
| 20 grms. of residue from pyridine extraction | 187 | 173 | 172 |
| 6 to 9 grms. of pyridine extract | 138–151 | 146 | — |
| Bromine absorption of 5 grms. of the | Gms. | Gms. | Gms. |
| coal | 0·7 | 0·6 | 1·0 |
| Residue from pyridine extraction | 1·9 | 0·3 | 2·6 |
| Pyridine extract | 0·0 | 0·0 | 0·0 |

The absence of bromine-absorbing compounds in the extracts agrees with the work of Fischer and of Dennstedt and Bunz, but it is difficult to explain the low ignition temperatures found for these extracts.

A considerable amount of work, mainly on the storage of coal, was carried out between the years 1908 and 1917 by

Parr and his collaborators, at the University of Illinois Engineering Experimental Station.

Parr and Kressman (1910) drew conclusions from their work which differ considerably from those of other workers. They stated that whilst the oxidation of coal is a continuous reaction over a wide range of time and conditions, and begins at ordinary temperature, in general it may be said that for a given coal a temperature exists below which oxidation is not necessarily ultimately destructive ; for if the external conditions are modified, oxidation may cease. Above this critical temperature oxidation proceeds, independently of outside conditions of heat preservation, to ultimate destruction. The temperature at which ' autogenous ' oxidation begins (140° C. to 160° C. in oxygen ; 200° C. to 275° C. in air) is the sum of numerous temperature components and is dependent not only on the external conditions, but more particularly on the fineness of division of the coal.

The course of heating up of the coal is given by Parr and Kressman as follows : The first stage is attributed to the addition of oxygen to the unsaturated portions of the coal, no carbon dioxide being formed. This action, at any rate with Illinois coals of high sulphur content, is of subsidiary importance to the action responsible for the second stage of heating, namely the oxidation of pyrites. This forms a positive source of heat, and may raise the temperature of the coal sufficiently to start the third stage, which is provided by the tendency of certain of the hydrocarbon compounds to oxidise at temperatures in excess of 120° C. to 140° C., with the formation of carbon dioxide and water and the production of much heat. This causes a rapid temperature rise to 200° C. to 275° C., when the fourth stage of autogenous reaction begins, with ultimate firing of the coal. A marked accelerating effect on these reactions is exerted by moisture, especially during

the oxidation of pyrites. In a later paper (Parr, 1917) further emphasis to the importance of pyrites is given.

The views of Parr and Kressman cannot be said to have received much support from later work. The division of the reaction into stages, and the fixing of a fairly definite critical oxidation temperature, do not seem warranted. For a given set of conditions a temperature is certainly reached above which the evolution of heat is greater than the heat loss, the coal then beginning to self-heat; but this temperature is so entirely dependent on the physical conditions as to have purely an empirical value.

Parr and Hadley (1914), by the extraction of coal with phenol, obtained an extract which they considered to represent the resinic or pitch-like portions of the coal, and a residue representing the degradation products of the original cellulosic material. The first contained the coking constituents of the coal, the residue being non-coking. Both extract and residue absorbed oxygen to a marked extent, but the cellulosic residuum had in general a greater avidity for oxygen than the resinic portion. Previous oxidation of the coal before extraction reduced the proportion of the phenol extract and also diminished the coking properties of the coal.

In 1913 a Departmental Committee on Spontaneous Combustion in Coal Mines was appointed by the Home Office, but since its sittings were suspended during the war much of the later evidence has not yet been published. According to the Minutes of Evidence (1st to 7th days), published in 1913, Wheeler put forward views regarding the mechanism of the reaction between coal and oxygen which are discussed in detail later (p. 212). Amongst other witnesses whose evidence is given in the same place is Bedson, who concurred with the generally held opinion that the heating of coal is due to the oxidation of certain easily oxidised substances which must

exist in coal. The unsaturated compounds present would come in this class of substances. As a measure of the ease of oxidisability, Bedson suggested the reaction of coal with potassium permanganate. Bedson also expressed the opinion that the easily oxidisable substances in coal would be found in the portion extractable by pyridine, since this portion undergoes a change on exposure to the air. He did not consider the presence of pyrites to be important, owing to the small quantity usually found.

The view that the first reaction between coal and oxygen is the formation of an addition compound or complex, put forward by Wheeler before the Committee on Spontaneous Combustion just cited, was reached independently by Porter and Ralston (1914) a little later. As the experimental work on which their opinions were based was of a different nature from that of Wheeler, this hypothesis seems to be well substantiated. In the first series of experiments by Porter and Ralston, coal was heated in a stationary atmosphere of oxygen, which was renewed with measured volumes when necessary. Phosphorus pentoxide and soda-lime were placed in close proximity to the coal to avoid interference by the products of combustion with the absorption of oxygen and its measurement. As it was, considerable error was introduced in experiments at temperatures above 140° C., owing to the slow diffusion and absorption of the carbon dioxide formed. Four coals investigated showed widely different rates of absorption of oxygen, a sub-bituminous Wyoming coal showing about ten times the absorptive power of a semi-bituminous West Virginia coal.

Using a bituminous Illinois coal of medium absorptive power, the effect of variation of several factors was considered, among which may be noted :

(1) Oxygen pressure. The absorption of oxygen was not

directly proportional to the oxygen-pressure, but fell off at very low pressures. The curve given may be compared with that obtained later by Winmill (1916).

(2) In a constant percentage of oxygen, the presence of up to 10 per cent. of carbon dioxide has no retarding effect on the oxidation, even at 200° C.

For the investigation of the nature of the oxidation reaction, experiments of a different type were made, designed to yield information regarding the products of combustion at various temperatures. One gramme of each dried coal was heated at the required temperature in a rapid current of dry air for an hour, the products of combustion being collected and weighed, as was the residual coal. Water was collected on glass wool containing phosphorus pentoxide, carbon dioxide in a very efficient Vanier potash bulb, and carbon monoxide similarly after oxidation to carbon dioxide by passage over iodine pentoxide at 150° C. to 170° C. Blank experiments were made, using nitrogen in place of air, and the results subtracted from those found with air. The changes in nitrogen were small except at temperatures high enough to cause appreciable distillation of the coal.

From the results obtained, Porter and Ralston concluded that at temperatures below 200° C. oxidation tends both to fix oxygen and to form products in which water predominates; while above that temperature there is little or no fixation of oxygen, and carbon dioxide becomes the main product. The temperature given is a general one and varies greatly with the coal used, some coals giving the simple decomposition products much more easily than others, according to the varying ease of decomposition of the unstable complex which is evidently formed between the coal and the oxygen. The formation of carbon monoxide at such low temperatures can only be the result of direct decomposition of such a complex.

A definite relationship appears to exist between the three simple products of oxidation. Although different coals yield products of different compositions at the same temperature, and the same coal yields products of different compositions at different temperatures, yet for any given percentage of one constituent in the products of reaction, the percentage of the other two are fixed according to a definite relation which varies with the coal. In general, as the temperature rises the ratio $\frac{CO_2 + CO}{H_2O}$ increases, while there is a more or less constant ratio between $CO_2$ and CO. When plotted on a ternary diagram representing the three constituents, the points obtained at various temperatures for each coal fall approximately on a straight line, indicating the relationship just described.

Porter and Ralston consider 'There is no indication, therefore, that a uniform complex is produced from different coals by oxidation, but it is probable that in each coal several different complexes are formed, the same ones occurring possibly in all coals, but in different proportions.'

From 1913 onwards a considerable amount of work has been carried on at the Doncaster Coal Owners' Research Laboratories, chiefly by Winmill and Graham. The greater part of this work was concerned with the quantitative measurement of the absorption of oxygen by coal and its dependence on various external factors, and the measurement of its heating effect, but until recently little was done to trace the cause of oxidation. 'The Absorption of Oxygen by Coal' (Winmill and Graham, 1913–1916, in ten parts) deals in Part I. with the rates of absorption of various portions of the Barnsley Seam and the effect of various factors, which, however, are dealt with more fully in later papers. The various parts showed similar rates of absorption at 30° C., with the exception

of the shale and 'mother-of-coal,' both of which showed little absorptive power. An attempt was made to explain the curve Rate of Oxygen Absorption/Time on the basis of two similar reactions, each obeying an equation $\log \frac{A}{X} = Kt$, where X and $t$ are rate of absorption and time respectively, but later work apparently showed there was no justification for such an attempt.

The method of experiment, which was followed in most of the later work, was to pass air at a constant known rate over the coal maintained at a constant temperature, the amount of oxygen absorbed being calculated from analyses, made at intervals, of the issuing air stream.

The residual coal was examined for sulphate, but in no instance was more than a trace found; hence the conclusion drawn that pyrites plays no part in the low temperature oxidation of the Barnsley coals.

To obtain a more accurate absolute value for the oxygen-absorption of a coal, a static method was employed (Part II.). The coal was sealed up with air in a flask and oxygen was added automatically to make up the deficit caused by absorption. The volume added, with an analysis of the final gases, gave the amount of absorption. At 30° C. Barnsley hard coal absorbed about 820 c.c. of oxygen per gramme in sixty days; the total final absorption was calculated to be about 840 c.c. per gramme.

Both the rate of absorption and the total volume of oxygen absorbed were found to increase markedly with increased temperature, although the form of the curve Rate of Absorption/Time did not change greatly (Part IV.). The rate of oxidation increased fairly regularly with temperature up to 100° C., but above this with much greater rapidity. The

larger increase in the amount of oxygen absorbed above 100° C. was assumed to indicate the commencement of a more general oxidation (*cf.* Mahler, 1913), as was also shown by the carbon dioxide evolved at that temperature, no carbon dioxide being yielded by the substances responsible for the low-temperature oxidation.

The various portions of the Barnsley coal seam showed similar variations with temperature (Part V.) as regards their absorptive power. From the detailed results, it appears that certain differences manifest themselves between the various portions of the Barnsley seam, but these differences are probably of less importance than other differences between the coals, for example, their moisture-contents and friabilities. Judged from the absorption rates only, the part of the seam most liable to inflammation is the Softs.

The influence of other factors on the rate of absorption was investigated (Part VIII.). The rate of oxidation, though increasing with increasing fineness of the coal particles, was clearly not proportional to their outer exposed surface, which in some manner is penetrated by the oxygen. The total quantity of oxygen absorbed was independent of the fineness of the coal, although the rate varied. When the coal was so fine as to pass a 200 × 200 mesh sieve, practically its maximum absorption rate was reached. The difference between coals of different sizes, as regards their absorption rates, decreased with increase of time, owing to the much slower fall of the oxidation rate of the coarser coals.

The effect of reducing the percentage of oxygen in the air was to reduce its rate of absorption by the coal, but not proportionately. However, there appeared to be a simple relationship between the two, in that the rate of oxidation is proportional to the square root of the oxygen percentage in

the air. The figures given show that this relationship holds with considerable accuracy. This work makes it clear that to reduce the oxygen percentage in the mine with the hope of hindering spontaneous combustion is useless; whilst the importance of keeping the goaves, etc., airtight is emphasised, since with the oxygen in the atmosphere even so low as 5 per cent. the oxidation will still proceed at half its normal rate in air.

In Part VII. of the Doncaster researches Graham (1915) considered the influence of moisture on the rate of absorption of oxygen by coal. 'Wet' oxidations were made with the air stream passing over a wet sponge in the reaction vessel containing the coal. In the 'dry' experiments, dried air was used, with a layer of calcium chloride above and below the coal. The coals used were free from visible pyrites. The results showed that the rate of oxidation of moist coal at 30° C. and 50° C. in a current of air saturated with moisture is greater than that for a portion of the same sample oxidised when dry, the rates of oxidation being on the average about 1·5 : 1. This is in agreement with the statement of Mahler (1913) that oxygen is absorbed more easily by coal when it is wet than when it is dry; and is contrary to some early results obtained by Richter (1870). Graham also observed that the rate of oxidation of coal dust was unaltered after heating at 100° C. in a vacuum during a considerable time, from which he concluded that bacterial activity has nothing to do with the absorption of oxygen by coal.

Turning to the products of the oxidation (Parts IV. and V. it was found that with none of the Barnsley coals used was any carbon dioxide formed during the initial oxidation. At higher temperatures the proportion of oxygen absorbed which was evolved again as carbon dioxide increased both with rise of temperature and with the duration of the experiment. For

example, the following results are obtained with Barnsley Hards :

$$\text{Ratio}: \frac{CO_2 \text{ production}}{O_2 \text{ absorption}} \text{ per cent.}$$

| | At 30° C. | At 100° C. | At 160° C. |
|---|---|---|---|
| After 2 hrs. | 2·8 | 4 | 20 |
| ,, 168 ,, | 7·1 | 20 | 50 |

The production of carbon monoxide ran parallel with that of dioxide, but the quantities obtained were much smaller. The ratio $\frac{CO \text{ production}}{O_2 \text{ absorption}}$ increased with the temperature and also with the duration of the experiment, reaching, however, approximate constancy after the thirtieth hour. The ratio $\frac{CO_2 \text{ production}}{CO \text{ production}}$ increased with time and decreased in general with increasing temperature. The method used, that of passing a stream of air over the coal and making frequent analyses of the issuing air-stream, is not delicate, and perhaps explains why Graham and Winmill found no appreciable production of the oxides of carbon during the initial oxidation at ordinary temperatures. (*See*, in this connexion, Katz and Porter (1917 B).) The production of water, relative to the absorption of oxygen, at temperatures below 100° C., was found by Graham (1916) to be considerable, varying little with the temperature, but increasing slightly with the time of oxidation. For example, with Barnsley Hards at 50° C. :

$$\text{Ratio} \frac{O_2 \text{ in } H_2O \text{ produced}}{O_2 \text{ absorption}}$$

| During first $5\frac{1}{2}$ hrs. | During next 45 hrs. | During next 100 hrs. |
|---|---|---|
| 28·5 per cent. | 35·7 per cent. | 39·2 per cent. |

The reaction responsible for the production of water is therefore different from that giving the oxides of carbon. As

regards its effect on the coal, the water produced is small compared with the natural moisture of the coal.

The thermal value of the absorption of oxygen, treated of by Winmill (1914) in Part III., had previously been investigated by Lamplough and Hill (1913). The last-named investigators carried out the oxidation in a vacuum flask immersed in a water bath at a regulated temperature. The rise in temperature was determined thermo-electrically, whilst the absorption of oxygen was followed by continuously recording the fall in pressure. Determinations were made on various coals, mainly from the Barnsley seams, and on pyrites. The conclusion was reached that the heat evolved is mainly proportional to the volume of oxygen absorbed, whatever the coal used; whilst pyrites gives a similar value. The mean result was 3·4 cals. per c.c. of oxygen absorbed.

In Winmill's repetition of these determinations the coal was contained in a vacuum flask immersed in a thermostat, maintained at 0·2° C. lower than the temperature of the coal, so that loss of heat was reduced to a minimum. A measured amount of oxygen was admitted and allowed to be absorbed, the final small residue of oxygen being estimated by sweeping out with nitrogen and analysing. From the rise in temperature of the coal it was calculated that when 1 c.c. of oxygen is absorbed by either Barnsley soft or hard coal, 2·1 cals. of heat are generated. Lamplough and Hill's values were criticised by Winmill on two grounds: (1) the effect of diffusion, which undoubtedly took place, and (2) the neglect to take into account the oxygen taken up by the coal immediately on its entering the flask. Correcting their figures as far as possible, Winmill showed that their thermal values are brought much nearer to his own determinations.

Winmill (1914) in Part VI. gave an interesting discussion of the conditions necessary for the spontaneous combustion

of coal. He suggested that: 'In considering the spontaneous heating of coal, it is clear that the primary problem is to determine how the coal begins to rise above the normal temperature of the face, goaf, or stack, and that considerations of what will happen to the coal after it has reached a certain relatively high temperature are so far secondary that they do not even touch the real problem of spontaneous heating, although they may have a bearing on the final conditions under which the coal fires. It follows therefore that there is no necessary connexion between the so-called 'points of inflammation of coal' and the liability to spontaneous heating.'

A detailed discussion of various conditions was then given; such as, when the curve of rate of production of heat lies completely above the loss of heat curve, or when at low temperatures the two curves lie thus during a certain temperature range. Under the latter condition spontaneous ignition cannot occur, even though the substance might be one commonly termed 'very inflammable.' It is suggested that the most accurate guide to the probability of spontaneous heating is given by a determination of the rates of oxidation. Winmill also described certain experiments in which coal, without external heating, fired by its own oxidation from room temperature.

On the whole, Winmill's arguments regarding the relative values of 'rates of oxidation' at low temperatures, and 'inflammation points' as criteria of the ignitability of a coal, are well founded.

Part IX. of this series of researches consisted of a comparative examination of many different varieties of coal, some liable to fire, others not, with a view to ascertain whether the explanation found adequate for the firing of the Barnsley coals, based on the reaction between the coal substance alone and the oxygen of the air, would hold good for other seams.

The original air stream method of absorption was adopted. The coals, ground to pass a 60 × 60 mesh sieve, were treated in the same way, and were examined for sulphate before and after oxidation, to distinguish between absorption of oxygen by pyrites and by the coal. For purposes of comparison, certain Barnsley coals were taken, in which pyrites had no influence on the absorption. The Barnsley Hards and Softs liable to fire had absorptions respectively of 350–450 and 475–500 c.c. of oxygen per 100 grammes of coal in 96 hours at 30° C.

A shortened summary of the many tables given appears on page 207.

The Barnsley coals having an absorption of 300–500 c.c. per 100 grms. at 30° C. are all liable to fire. The South Wales anthracites show similar absorptions to the Barnsley coals at 30° C., but at 60° C. there is a great difference, for the anthracites absorb very little more at this temperature than at 30° C. ; whilst the Barnsley coals absorb three times as much as at 30° C. The anthracites appear to have a definite small capacity for oxygen. The same holds for the steam coals, which also have a very low value for their absorption at 30° C. It is suggested that the freedom from fires in the Northumberland and Durham area is due to the low oxygen absorption of the coals, less than 300 c.c. per 100 grammes at 30° C., which amount is considered to be the border-line. Owing to exceptionally good pit conditions Coal No. 7, despite its very high absorption, is free from fires. Above ground it fires in stacks and cargoes. With the very easily ignited Bullhurst coals, the oxygen absorption, even including that due to the pyrites present, is small, and is, according to Winmill, too low to explain the heating that takes place in the seam. It is suggested that the heating is due to the presence of finely divided pyrites mixed with a little coaly material, in a very oxidisable form, in some places in the seam, and that at these

| Coal. | No. | Oxygen absorbed per 100 gms. of Coal in 96 hours. At 30° C. c.cs. | At 60° C. | Remarks. | |
|---|---|---|---|---|---|
| I. Barnsley Hards | A, B, C | 453 | 1150 | No pyrites oxidation. | Liable to fire. |
| | E | 340 | — | | |
| Barnsley Softs | A, B, C, D, E | 300–500 | — | | |
| II. S.W. Anthracites | 13 | 273 | — | No pyrites oxidised. | Free from heating. |
| | 14 | 381 | 450 | | |
| III. S.W. Steam Coals | 8 | 100 | 133 | No pyrites oxidised. | Free from heating. |
| | 9, 10, 11, 12 | 80–134 | — | | |
| IV. Northumberland and Durham | 1 | 527 | — | Also pyrites. | Occasional fires. |
| | 2, 3, 4, 5, 6 | 100–300 | (5) 220 | | Almost free from fires |
| | 7 | 623 | 1,305 | | No fires. |
| V. Bullhurst Seam, N. Staffs | 15, 18 | 133–167 | — | Including oxidation of pyrites. | Liable to fire. |
| | 16 | 132 | 273 | | |
| | 17 | 167 | 292 | | |
| | 19 | 107 | 164 | | |
| VI. Thick Coal, S. Staffs | 38, 39 | 510–530 | — | No pyrites. | All very liable to fire. |
| | 40 | 400 | — | Including pyrites. | |
| | 41 | 294 | — | | |
| | pyritic material 42 from parting | coal 225 pyrites 131 | — | Containing 54 per cent. pyrites. | |
| VII. Ayrshire Coals | 33, 34 | 502 | (34) 1100 | | This pit has fires. |
| | 35 | 392 | — | | |
| | 36 | 124 | — | | |
| VIII. Lignite from Portrush | 37 | 476 | 3800 | | No fires ; wet mine. |

points the necessary initial heating takes place. The same explanation does not hold for the thick South Staffordshire coals, which themselves would provide sufficient heat for spontaneous combustion. There are present large veins of pyrites, but not in an oxidisable condition.

The absorption curves for all the coals were of the same type, but varied considerably in magnitude. Classifying the coals on the basis of the quantity of oxygen absorbed during the first 96 hours at 30° C., Winmill gave the following three main divisions:

(1) Coals which have a small definite capacity for oxygen which is not altered by moderate increase in temperature, and therefore cannot fire spontaneously—*e.g.* anthracites and Welsh steam coals.

(2) Coals with a low rate of oxidation, the capacity for which increased with temperature. Not liable to fire unless mixed with pyrites.

(3) Coals with a large oxidation rate, sufficient itself to cause firing.

There seems to be no gradual transition between classes (2) and (3). Coals not liable to fire absorb generally under 200 c.c. per 100 grammes; those liable to fire usually well over 300 c.c. of oxygen under the given conditions.

Mention must be made of the later work of Graham (1916, 1919) on the permeability of coal to gases, and on the solubility of gases in coal. The results showed that solid coal is practically impermeable to gases. Hence coal a very little way inside a solid block, even though the block may have been standing exposed to the air during many years, behaves like fresh coal towards oxygen.

The solubility of various gases in coal was found to be great. For example:

Volume of gases absorbed per 100 gms. of coal: c.c. at N.T.P.:

| | $CO_2$ | $CH_4$ | CO | $N_2$ | $H_2$ |
|---|---|---|---|---|---|
| At 30° C. . . | 800 | — | 71·2 | 57·6 | 6·81 |
| At 100° C. . | 148 | 47·6 | 15·9 | 11·5 | 3·80 |

With the more soluble gases equilibrium is attained in several hours, with the less soluble, more quickly. As would be expected, the solubility decreases rapidly with rise of temperature. For the less soluble gases, the amount dissolved is practically proportional to the concentration of the gas over the coal—a rather remarkable result.

The conclusions arrived at by the Doncaster investigators are summarised briefly in a paper by Haldane (1917), who also considered the possible preventive measures.

A valuable contribution to the chemical aspect of the subject was made in 1917 by Graham and Hill (1917), who showed that practically the whole of the absorption of oxygen by coal appears to be due to the residue obtained after extraction with pyridine : the pyridine extract showing a remarkably low absorptive power. Oxidations were carried out at 30° C. and at 90° C. The results obtained at the latter temperature were as follows :

Table IV.

| Coal. | | Extract (10 per cent. of coal). | | Residue. | |
|---|---|---|---|---|---|
| After Hours. | Rate of Absorption c.c. $O_2$ per Hour per 100 Grms. | After Hours. | C.c. $O_2$ per Hour per 10 Grms. | After Hours. | C.c. $O_2$ per Hour per 90 Grms. |
| 1·25 | 155·0 | 1·25 | 2·1 | 1·50 | 145·6 |
| 18·75 | 35·45 | 18·75 | 0·87 | 18·75 | 38·8 |
| 26·25 | 30·0 | 25·75 | 0·81 | 25·75 | 29·7 |
| 43·75 | 24·45 | 50·55 | 0·57 | 50·55 | 20·7 |
| 69·75 | 18·0 | — | — | 69·0 | 16·0 |

The extractions of the coal used (Barnsley Softs) were carried out in an atmosphere of nitrogen at 40° C. under reduced pressure. The oxidations were effected in a special apparatus, in which the dried coal was maintained in contact with dried oxygen at the required temperatures, diffusion being aided by a syphoning attachment, which alternately reduced and increased slightly the pressure of oxygen in the reaction flask.

Katz and Porter (1917 A) found that during the oxidation of coal at low temperatures no water was produced. This is not in agreement with the conclusions of previous workers (Mahler (1913) ; Graham (1916) ). The method used was to measure the vapour pressure of the coal by absorbing in phosphorus pentoxide and weighing the moisture taken up by the atmosphere passing over the coal. The coal was dried by the passage of dry nitrogen until its vapour pressure had reached a certain low value, at which it remained almost constant. Alternate air and nitrogen was then passed over it. The absence of break, as the change in atmosphere was made, in the curve connecting the water taken up per litre with the volume of gas passed over was taken as evidence of the non-formation of water during oxidation. In a later paper (1917 B) these authors examined the effect of moisture and the production of the oxides of carbon during low temperature oxidation. Most of the oxygen remained in the coal as addition compounds. As regards the ease of oxidation in a moist or dry atmosphere, it was found that one coal oxidised most in moist air, another most in dry.

Charpy and Godchot (1916) investigated the changes in weight and calorific value of coal on oxidation. Their work is a confirmation generally of the previous work on this aspect of the subject, except that they state that the content of

volatile matter is unaffected by oxidation. This is in opposition to the results of the majority of workers.

A short account of the subject of the spontaneous combustion of coal has been given by Bone (1918). A preliminary description of certain oxidation experiments is given, in which oxygen was circulated continuously over coal, the rate of absorption and the nature of the products of oxidation being noted. Two coals were used—a Durham coking coal and a Barnsley hard steam coal having nearly the same ultimate analysis. Below 80° C. absorption was stated to be slow, but it quickened decidedly above that temperature ; above 100° C. oxides of carbon and steam were simultaneously evolved. Absorption of oxygen was long-continued and was not complete after 400–700 hours at 107° C. to 109° C. The two oxides of carbon were continuously and simultaneously produced throughout each experiment, and after the first 100 hours in nearly the same relative proportion $\left(\frac{CO_2}{CO} = 2 \cdot 5\right)$. The proportion of the oxygen absorbed appearing as oxides of carbon was also almost constant (15 per cent. for coal A and 18 per cent. for coal B). The proportion evolved as steam was from 30 to 35 per cent. These results should be compared with the somewhat similar figures obtained by the Doncaster Research Laboratory over a wide range of temperature.

The most recent studies on the spontaneous combustion of coal are those involving the differentiation of the four macroscopically distinct ingredients into which banded bituminous coal can be separated, and the investigation of the mechanism of the oxidation process.

Stopes (1919) has shown that the four constituents, vitrain, clarain, durain, and fusain, separable from banded bituminous

coal differ not only in general appearance, but also in their morphological structure as revealed by the microscope and in their resistance to the various treatments used for their clarification before such examination. These differences were found by Tideswell and Wheeler (1919 A) to extend in some degree to the chemical compositions (*see* Table VIII., page 233). Their results suggested that, with the exception of fusain, the differences between the ingredients are not essentially due to any fundamental differences in the types of compounds of which they are composed, but rather to the relative proportions in which such types of compounds (which may be divided into 'reactive' and 'inert' groups) exist in the various ingredients. Marked differences were also found by Lessing (1920) in the behaviour of the coal ingredients towards coking and to an even greater extent in their ash-contents, especially between durain on the one hand and vitrain and clarain on the other.

This division of the coal into distinct ingredients renders necessary their separate consideration when dealing with the spontaneous combustion of coal. Such large differences in reactivity towards all the treatments used in their investigation should almost certainly be accompanied by a similar variation in their reactivity towards oxygen. The direct investigation of this question (Tideswell and Wheeler, (1920)), showed that of the three main ingredients, the bright ones, vitrain and clarain, were considerably more liable to oxidise and to ignite than the dull durain (see page 236). Fusain was relatively more easily oxidisable at low temperatures, but not at temperatures of 100° C. or higher.

The mechanism of the reaction between coal and oxygen was treated by Wheeler (1913, 1918), who found a great similarity between the modes of combustion at low temperatures of carbon and of coal. The mode of combustion of

carbon (*see* Rhead and Wheeler, 1912–1913) is characterised by the absorption of a considerable amount of oxygen without the appearance of the corresponding amounts of the usual gaseous products of combustion, the oxygen combining with the carbon in the form of a physico-chemical complex from which it cannot be removed by evacuation only. Exhaustion of the carbon at higher temperatures, or continued passage of oxygen after the carbon has become 'saturated,' results in the decomposition of the complex with simultaneous formation of carbon monoxide and dioxide, which are produced in a fixed ratio dependent on the temperature of reaction. Very similar results are obtained with coal, a complex of the same type being formed, which on exhaustion at a higher temperature decomposes; a considerable portion of the absorbed oxygen makes its appearance as oxides of carbon and water, while the coal recovers to a large extent its original absorptive power.

In the same publication Wheeler discusses the variations in the tendency to ignition of coals (as shown by 'ignition-temperature' experiments), and points out their close connexion with the oxygen-content. The relationship that the higher the oxygen-content the lower will be the ignition-temperature was found to hold very closely throughout the large class of bituminous coals.

The views of Wheeler on the mechanism of combustion of carbon and of coal were questioned in a theoretical paper by Partington (1919), who attempted to explain Wheeler's results on the basis of a purely physical absorption of oxygen, followed by direct formation of carbon monoxide and subsequently of carbon dioxide (and, in the case of coal, of water). These arguments were answered by Tideswell and Wheeler (1919 B), who showed that such a hypothesis is quite inadequate to explain quantitatively the results obtained, although it

may at first sight afford a plausible explanation of the phenomena qualitatively. Further experimental data brought forward showed that the reactions suggested by Partington were negligibly slow at temperatures such as were concerned in the spontaneous oxidation of coal.

The later work, referred to above, on the reactivity of the four ingredients of banded coal towards oxygen, has given results which fully confirm the views held on the mechanism of the reaction between coal and oxygen.

TABLE V.

*Gases Evolved on Exhaustion.*

| Temperature during exhaustion. | *A* From durain, after oxidation at 100°. C.c. | | *B* From same sample of durain (after experiment *A*), after oxidation at 50°. C.c. | |
|---|---|---|---|---|
| | $CO_2$. | CO. | $CO_2$. | CO. |
| 15–100° . . | 2·7 | 0·7 | 3·1 | 0·8 |
| 100–150° . . | 18·5 | 5·2 | 4·5 | 1·6 |
| 150–200° . . | 63·8 | 15·1 | 15·8 | 4·5 |

From a study of the quantities and compositions of the gases obtained by exhaustion at higher temperatures (up to 200° C.) of the oxidised coals, it was shown that

(1) There is a rapid and continuous increase in the amount of gas evolved (that is to say, in the amount of decomposition of the coal-oxygen complex) as the temperatures of exhaustion of the coal, after oxidation, is increased (*see* Table V).

(2) The amount of complex formed, as judged by the volumes of carbon dioxide and carbon monoxide subsequently evolved on exhaustion at 200° C. increases rapidly with the temperature of oxidation.

These views of the physico-chemical nature of the complex formed between coal and oxygen may be compared with those reached by Porter and Ralston (1914) derived from experimental data of a rather different type.

### *The Effect of Bacterial Activity*

Bacterial activity is known to play a large part in the oxidation and consequent combustion of many substances; the best known example is that of hay, in which the liability to fire when stacked is due almost entirely to bacterial growth. The bacteria effect rapid oxidation of the organic matter, and although they are destroyed by the high temperature eventually resulting, the mass has received the necessary impulse for spontaneous combustion to ensue, unless checked, by purely chemical oxidation.

It has been suggested that such an action may be a cause contributory to the heating up of coal in air. Potter (1908) found that the presence of bacteria assisted the oxidation of charcoal. Ordinary wood charcoal was heated to 1200° C. and cooled in absence of air, and samples were placed in sterilised flasks and sterilised. Several of the flasks were treated with bacteria diplococcus (from soil) and air then drawn through the treated and untreated flasks, both of which were maintained at 20° C. During the first week no carbon dioxide was evolved from either group of flasks; at the end of this time carbon dioxide was evolved from the treated flasks only. Moreover, experiments in which heat-losses were minimised showed a heating effect with the treated charcoal, but not with the sterilised charcoal. Similar results were obtained with lamp-black, peat, and coal. Antiseptics had apparently no effect in preventing carbon dioxide formation; nor did those used (mercuric chloride, iodine, and chloroform) destroy the bacteria.

Potter gave the following figures, showing the effect on carbon dioxide formation :—

TABLE VI.

| Temperature. . . . | | 20° C. | 30° C. | 40° C. | 100° C. | |
|---|---|---|---|---|---|---|
| Coal . | Moist, inoculated | 2·0 | 3·1 | 4·6 | nil | Milligrams of $CO_2$ formed per five grams in 20 days. |
| | Moist, sterilised by boiling . | nil | nil | nil | nil | |
| | Dry . . . | nil | nil | nil | nil | |
| Charcoal | Moist, inoculated. | 0·77 | 1·1 | 2·5 | nil | |
| | Moist, sterilised . | nil | nil | nil | nil | |
| | Dry . . . | nil | nil | nil | nil | |

Potter concluded that a slow oxidation of amorphous carbon or coal takes place through the agency of bacteria, carbon dioxide being evolved. The amount of carbon dioxide given off increases in proportion to the rise of temperature and ceases to be evolved at a supra-vital temperature (*i.e.* 98° C. to 100° C.). There is no evolution of carbon dioxide under perfectly dry conditions such as preclude the possibility of bacterial life. At the same time, the action of the bacteria causes a distinct rise in temperature. Potter considered that this heat generated by micro-activity is an influence to be taken into account in connexion with the spontaneous combustion of coal.

Galle (1910) made a bacteriological study of different coals under both aerobic and anaerobic conditions, and showed the presence of seven different kinds of bacilli, of which three were identified. These develop at the normal temperature and without air, and in one experiment non-sterilised coal, moistened with tap water, gave a luxuriant growth of bacteria.

Four of these seven kinds, when grown on the coal, produced a gas containing from 5 to 27 per cent. $CO_2$ and

from 71 to 85 per cent. $CH_4$, with small amounts of carbon monoxide.

The bacterial action is accompanied by a slight rise in temperature, the maximum effect observed being 2° C. It was, however, found that coal which has been subjected to the action of bacteria ignites at a lower temperature than the original coal. Galle concluded that whilst bacteria are not the immediate cause of spontaneous ignition of coal, they play an important part in the production of the conditions which result in ignition.

Winmill (1914) put forward, as an argument against this bacterial theory, that the characteristic shape of the oxidation-rate/time curve persists over a large range of temperature, even up to 160° C., which would not be expected were the reactions responsible for the oxidation of a quite different nature at low and at higher temperatures. Graham (1915) attempted a more direct proof, by comparing the rates of oxidation of a coal with that of a sample which had been preheated to 100° in a vacuum during several hours. No difference was found, from which it was concluded that bacterial oxidation was absent. However, although the heating at 100° would destroy bacteria present in the coal, no precautions seem to have been taken to sterilise the apparatus used, or the air stream, consequently the experiment is robbed of the conclusiveness it might otherwise have had.

Reverting to Potter's work, it is difficult to understand why no appreciable amount of carbon dioxide should have been produced during the oxidation at 100° C. On the basis of other work on the products of oxidation of coal, dry or moist air should yield at this temperature, in twenty days, from 10 to 100 or more milligrammes of carbon dioxide from the 5 grammes of coal used, depending on the properties of the coal investigated.

On the whole, it must be concluded that, although there is strong evidence (1) that coal is a favourable medium for the growth and life of bacteria, and (2) that bacteria suitably grown in the presence of coal exert an influence on its decomposition and oxidation, there is as yet little evidence either for or against the suggestion that spontaneous combustion is influenced appreciably by bacterial activity.

### *The Influence of Moisture.*

An opinion generally held amongst those engaged practically with the spontaneous combustion of coal is that moisture exerts a marked accelerating influence. For instance, Threlfall (1909) has stated, with reference to the English Commission of 1876: 'Out of twenty-six answers to questions as to the effect of moisture, every reply was to the effect that moisture was a source of danger.' It is surprising, therefore, to find that 'an examination of the reported evidence shows that in every case (with a single exception) this was a matter of impression only.'

In discussing the influence of moisture on the spontaneous combustion of coal, care must be taken to differentiate between the several parts which the water may play in such an action. These different effects may be summarised as follows:

(1) The presence of water vapour may influence the rate of the reaction between oxygen and coal.

(2) The presence of moisture in the coal and in the atmosphere has an important physical effect (*a*) on the preliminary solubility of oxygen in the coal and (*b*) on distribution of the heat generated by oxidation.

(3) The natural moisture content of the coal, which has often been suggested as a measure of the liability to spontaneous combustion, must be considered. It seems likely that the connexion between the absorption of moisture and of

oxygen arises from the dependence of both on some third as yet unknown factor, and is not due to the fact that the absorption of oxygen is actually dependent on the amount of water present. This phase of the subject will therefore be dealt with when discussing the influence of the composition of the coal on its spontaneous combustion.

As regards (1), the presence of water vapour is known to exert a marked accelerating influence on the progress of many reactions, a well-known example being the combustion of carbon. It is strange, therefore, that in the combustion of coal, which so much resembles in mechanism that of carbon, this effect of water vapour should be debatable.

Richter (1870) decided definitely against the accelerating influence of water vapour. He stated: 'If we take two tubes, and into one of them introduce air-dried, and into the other moist, coal, both being freshly won, the first absorbs oxygen much more quickly than the second. If, in addition, small bulbs containing fused calcium chloride are introduced alongside the dry sample of coal, so that the coal gets gradually drier, the intensity of absorption of oxygen becomes greater. The same is the case if the coal has been dried for a day over sulphuric acid, although during this process a very considerable quantity of oxygen must certainly have been taken up.' The reverse was found to hold when the coals contained a large amount of pyrites (3 per cent.), but the effect was slight.

Fischer (1899) obtained indeterminate results; with some coals the presence of water accelerated, whilst with others it retarded, both the absorption of oxygen and the formation of carbon dioxide.

Mahler (1913) found that coal, in the presence of oxygen under pressure, absorbed considerably more when moist than when dry.

Graham (1915) found the rate of oxidation of coal to be one

and a half times as great in a moist as in a dry atmosphere. For example, at 50° C. :

Table VII.

| | After Hours. | | | | | |
|---|---|---|---|---|---|---|
| | 2 | 4 | 8 | 30 | 60 | |
| A. Dry coal, dry air. | 25·2 | 18·8 | 12·6 | 6·4 | 4·4 | c.c. $O_2$ per hour per 100 grms. dry coal. |
| C. Dry coal, moist air | 36·5 | 29·5 | 20·3 | 8·9 | 6·2 | |

The coal used was free from pyrites. Tests were made with one coal only (Barnsley ' Hards ').

Katz and Porter (1917 B) compared the rates of absorption of oxygen by a coal at 26° C. when dry and when wet. The ' dry ' experiments were made with dry $O_2$, and coal dried in a vacuum or in nitrogen over phosphorus pentoxide, which was also present in the reaction flask. In the ' moist ' experiments, the oxygen and the coal were both in equilibrium with moisture, which also took the place of the phosphorus pentoxide in the reaction flask. The results obtained varied with the coal used ; thus with an Illinois coal, the rate of oxidation was slightly greater when dry than when moist, whereas a dried sample of Pittsburgh coal oxidised at a slightly slower rate than a comparatively moist sample of the same coal. The initial rates were always greater with the dried coals, but fell off very rapidly.

Comparing their results with those of previous workers, Katz and Porter conclude : ' Evidently the rates of oxidation of different coals are not affected uniformly by moisture. . . . It seems doubtful whether water, other than the excess which actually wets the coal, plays an important part in the rate at which coal oxidises at the lower temperatures, with consequent increase in the danger of spontaneous combustion.'

This view must be taken as the only one warranted by the evidence at our disposal.

When water is present in excess amongst the coal, different considerations arise. The wetting of the coal will reduce the proportion of open spaces in the mass, especially if the coal is finely divided, with the result of obstructing the flow of air through the pile, thus reducing ventilation and heat dissipation, but also the amount of oxidation. The water taken up in the coal substance itself will also reduce the initial rapid absorption of oxygen. Which effect will predominate depends on the conditions obtaining.

A further effect is the cooling action of the water, which by its large latent heat of evaporation hinders the coal from rising above a certain temperature (80° C. to 100° C.). In a large heap, however, this cooling effect is lost, as the water condenses in other parts of the heap, with resulting rise of temperature there.

Examining the practical effect of water on the heating of heaped coal, Fayol (1879) could not form any definite general conclusions. The second New South Wales Commission (*see* Threlfall, 1909) found an important cooling effect of the added water. Whilst untreated coal stored in a bin fired in about ten weeks, coal which had been sprayed with water whilst being unloaded rose only slightly in temperature at first and afterwards slowly fell again.

In the presence of pyrites moisture appears to help oxidation and consequent heating (*see* Richter, 1870). Parr and Kressman (1910) also found that wetting an Illinois coal of high pyritic content increased the rate of heating with fine coal but not with larger coal. With coals of low pyritic content, wetting decreased the rate of heating for coals of all sizes. It has also been suggested that where the coals contain pyrites in any quantity, wetting may further the oxidation of this constituent,

with the result that, the crystalline products occupying a considerably larger volume than the original pyrites, the coal may be split up into small fragments, favouring rapid oxidation. On the whole the wetting of coal, as a preventive of spontaneous combustion, seems therefore to be a somewhat doubtful expedient, unless carried out very thoroughly.

*Pyrites as a Factor in the Spontaneous Combustion of Coal.*

During the history of the researches on the spontaneous combustion of coal, no question has been more widely or more vigorously debated than that of the responsibility of pyrites. The varying conclusions which have been reached on this point are not surprising when the different experimental methods, the different coals, and especially the very different forms in which pyrites may exist, are taken into account.

Iron sulphide exists in many crystalline forms, of which the two most important are the cubical, generally referred to as 'pyrites,' and the orthorhombic, or 'marcasite.' The two differ considerably, the latter being more easily 'weathered' than the former, though they are not readily distinguishable in the absence of their crystalline form. Both varieties occur in coal. A third crystalline form occurs as 'radiated pyrites.' Apparently pyrites also occurs in coal-seams as an amorphous dark mass intimately mixed with coaly material, though possibly here also the structure may be finely crystalline.

Pyrites often occurs naturally as crystalline masses, possessing the form of the original organic matter, *e.g.* roots, wood, &c., which it has replaced. Lomax (1914) has described two forms of this type, which he found finely disseminated through the coal mass; in both, portions of the organic matter seem to have been replaced by pyrites without alteration of the morpho-

logical structures. Lomax has named these forms: (1) 'Pyritica Stellata,' starlike bodies suggested to be of animal origin and found in various stages from the non-pyritised to the completely pyritised structures—no oxidation of these seems to occur; and (2) 'Globulites,' tiny globular bodies which, like the first-named, may be partially or completely pyritised. The fully pyritised 'Globulites' show no signs of oxidation, but when the surfaces only are pyritised, oxidation may be seen to take place rapidly, the formation becoming covered with a white deposit, or only a hollow cup-like form being left.

It should be stated that Lomax's observations are based throughout on purely microscopical data, no chemical evidence of the pyritisation or of the oxidation being obtained.

Pyrites in the usual form of large cubic crystals is very stable, the surface brightness not suffering even after long exposure to the air. Marcasite is not so stable, while finely divided pyrites is readily oxidised. The presence of water is stated to be necessary for the oxidation process, which is usually represented by the equation:

$$2FeS_2 + 7O_2 + 2H_2O = 2H_2SO_4 + 2FeSO_4.$$

Further oxidation to ferric sulphate may finally take place.

The work of Richter (1869, 1870) showed that the oxidation of the coal substance itself is generally sufficient to account for the spontaneous combustion of coal, independently of any contribution which pyrites might make to this end. The evidence brought forward by Richter was the large absorptive power for oxygen of coals known to have a remarkably low content of pyrites, and the much larger heat production than he considered could be accounted for by the complete oxidation of any pyrites present. No tests for the presence of sulphates after oxidation were made. Richter further found that the

oxidation of pyrites may take place only very slowly, especially in dry air.

Fayol (1879) arrives at similar conclusions, his experiments indicating that pyrites did not affect the oxidation of the coals used.

In spite of this work, belief in the responsibility of iron pyrites for the firing of coals continued, and was actively revived by Haldane and Meacham (1898). As a result of later work, however, Haldane has since modified his views considerably.

Dennstedt and Bunz (1908) rejected the pyrites theory completely, finding no relation between the ease of ignition and the pyrites content of the many coals they tested.

Parr and his co-workers (1910) attributed a certain share of the heating of coal to the oxidation of pyrites, though considering that this action waits upon an initial temperature rise, such as results from the absorption of oxygen by unsaturated compounds in coal. The amount of pyritic oxidation, with corresponding heat production, was found by Parr to be proportional to the pyrites-content of the coal, about 19 per cent. of the pyrites present being oxidised to the sulphate in 72 hours under the experimental conditions. For a coal containing 5 per cent. of pyrites, the authors estimated that this oxidation would raise the temperature of the coal mass by 75° C. They concluded 'It seems therefore that the presence of pyrites is a much more important factor in the spontaneous ignition of coal than has heretofore been considered, and its influence on the spontaneous combustion of coal cannot be discarded in the off-hand way which has been so common . . . merely because of the fact that some coals containing no pyrites would ignite spontaneously.'

Later, Parr (1917) traced the growth of sulphate on oxidation, with the time and the effect of fineness of division, and

found that coal passing through 10 mesh showed no signs of sulphur oxidation, while the fine coal generally showed considerable pyritic oxidation, after six months at room temperature (*cf.* above) in the presence of free moisture. The amount of oxidation was followed by determinations, before and after, of the $SO_3$ content. ' It is not intended to minimise the effect of oxidation of the organic matter as a source of heat, independent of the activity of the sulphur. In bituminous coals the two doubtless proceed independently, but where the activities exist together there is an acceleration of the reaction due to rapid rise of temperature.'

The work of the Doncaster Laboratory also gives some importance to pyrites. The early views of Haldane (1898) that pyrites were the main cause of spontaneous combustion had been modified by the results obtained by Graham and Winmill (1913, 1914) with the Barnsley coals ; these coals, which are very liable to spontaneous heating, contain little pyrites ; and further, after oxidation at moderate temperatures, little or no pyritic oxidation is found, showing that pyrites play no part in the early heating. Later, however, it was found that certain coals (*e.g.* North Staffs, Bullhurst Seam), whilst liable to fires, had low rates of oxidation, and attention was again directed to pyrites.

The heat value of the oxidation of pyrites had been found by Lamplough and Hill (1913) to be similar to that of coal, about 3·3 cals. per c.c. of oxygen absorbed. A re-determination of these values by Winmill (1914, 1916), using an improved method, gave the result 4·3 cals. for pyrites (agreeing with the calculated value), as against 2·1 cals. for coal, per c.c. of oxygen absorbed. In view of the high heat evolution, a series of determinations of the rates of reaction of pyrites was made. The results indicated that the large differences of ease of oxidation observed between various natural pyrites are due to their physical condition.

Grinding apparently reduces the samples to a common level :

| Sample . . . . | A. | B. | C. | D. | |
|---|---|---|---|---|---|
| | c.c. | c.c. | c.c. | c.c. | |
| Oxygen absorbed in 96 hours . . . | 1065 | 853 | 913 | 53 | Calculated to 100 per cent. pyrites. |
| Oxygen absorbed in 168 hours . . . | 1670 | — | 1383 | — | |

A and B are the same sample of Bullhurst pyrites containing 80 per cent. $FeS_2$; A being through 60 mesh, and B through 10 and on 30 mesh.

C and D are a very stable Barnsley Seam pyrites (98 per cent. $FeS_2$) ; C through 200, D through 10 on 30 mesh.

It will be seen that after grinding the difference between the two samples is small. The greater resistance of the Barnsley pyrites, as naturally occurring, is due to its crystalline nature, the crystal face being very resistant to chemical action. The North Staffs pyrites occurs in intimate admixture with the coal.

The absorption rate/time curve for pyrites falls off more slowly than that of coal, the decrease in the rate being due to the formation of a surface film of $FeSO_4$. From a comparison of samples C and D (see above) the rate of reaction appears to be proportional to the surface exposed. No preliminary absorption of oxygen takes place ; the rate of oxidation is proportional to the oxygen content of the atmosphere, while its temperature coefficient is large ($K_{10} = 2{\cdot}0$). Evidently the oxidation of pyrites is a simple chemical reaction, and differs in character from that of coal.

From his results Winmill calculated that a sample of pure pyrites can self-heat from 30° C. to 90° C. in three hours, as against

48 hours for the average bituminous coal. This explains some rapid ignitions of small heaps of coal which have been observed in a North Staffs mine. In the presence of much other material the effect of pyrites is masked, though it may still add its quota to the heat generated.

It is clear from these results that where finely divided pyrites occurs in considerable concentration among coal it may be the chief factor in originating combustion, but only under these conditions, lump or vein pyrites contributing nothing to the initial heating. With regard to the Bullhurst coal mentioned, it is evident from the small oxygen absorption that this coal cannot, even with its usual pyrites content, be responsible for the initial heating. In places, however, there is a high percentage of pyrites in a finely divided condition mixed with the coal, and it must be at these points that the initial impulse is given.

Owing to the larger variation of rate of absorption of oxygen with the oxygen content of the atmosphere, the relative importance of the pyrites, as compared with the coal, is reduced in such places as have a lowered oxygen content, *e.g.* in the goaf.

Drakely (1916) investigated the effect of the presence of pyrites on the absorption of oxygen by coal or the formation of carbon dioxide, but with inconclusive results. Addition of pyrites was found to increase largely the $CO_2$ produced from a coal on oxidation; ferrous sulphate had a similar effect, but moistening with sulphuric acid had a reverse effect. To explain some of the absorption results, a suggestion originally made by Richter was put forward, that alternate oxidation and reduction of ferrous sulphate occurs, the iron acting as oxygen carrier to a certain very easily oxidised portion of the coal. The conclusion was reached that pyrites, although a subsidiary factor, is not negligible in the spontaneous combustion of coal.

Drakely (1917) answered an argument put forward by Lewes (1912) to the effect that pyrites can have no connection with the heating of coal, inasmuch as $H_2S$ and not $SO_2$ is found in the neighbourhood of a gob fire. Drakely showed that $H_2S$ may be formed from heated coal in a variety of ways, *e.g.* by simple heating, by the passage of $SO_2$ over the coal, by heating coal with sulphur or iron pyrites, or by passing water vapour or hydrogen over heated pyrites. Therefore, although $SO_2$ might be formed in a gob fire, it would, if not completely reduced immediately to $H_2S$ in the vicinity of the heated coal, encounter much larger volumes of $H_2S$ issuing from the heated surrounding coal and be decomposed.

A consideration of the researches herein reviewed leads to the conclusion that it would be almost as great an error to ignore completely the presence of pyrites in coal as it was to impute to it the full responsibility for spontaneous combustion. Oxidation of the coal substance and oxidation of pyrites work together for the ultimate firing of the coal. In general the former is by far the major factor, the relative values of the two actions being conditioned on the one hand by the chemical activity of the coal towards oxygen and its physical condition, and on the other hand by the state of occurrence of the pyrites, whether as 'coal-brasses,' or in a finely divided condition. A local concentration of an active form of pyrites may be more dangerous than the same distributed uniformly through the coal.

### *The Constitution of Coal and its Liability to Spontaneous Combustion.*

It has long been recognised that there is no close connexion between the proximate and ultimate analyses of a coal and its liability to ignite in air. Coals of different classes may however be differentiated, the ease of ignition decreasing steadily

according to the degree of 'carbonisation' of the coal. Thus the lignites are the most easily oxidisable; then follow the various grades of bituminous coals, the steam coals, and the anthracites, the last-named seldom giving trouble through heating.

From the analytical determinations, however, two values may be excepted. There is some evidence that the general rule that the higher the moisture content and the oxygen content of a coal the more readily ignition occurs, holds not only to distinguish between the various classes of coal, but also with considerable accuracy throughout the class of bituminous coals.

*Moisture Content.*—Richter (1870) found a close connexion between the power of a coal for taking up water and for absorbing oxygen, and pointed out that although the absorption of oxygen is not a physical action, the effect of surface action of the coal is not to be overlooked.

Dennstedt and Bunz (1908) also pointed out the relationship between the moisture content of coals and their liability to ignite, as determined in ignition experiments. Their table of results (see page 192) does not, however, illustrate this very clearly.

Winmill (1916) considered a high natural moisture content to be a fair indication of the extent to which oxygen absorption would take place, but gave no examples. An examination of his tables of rates of oxidation (at 30° C.) for various coals shows that the relationship in general holds closely, but there are a few marked exceptions.

The hydroscopic water of a coal does not, of course, itself exert much influence in the oxidation of the coal, except by virtue of its physical effects, which are discussed elsewhere. Probably the moisture content must be looked on as a measure of a physical property of the coal—its power of condensing

vapours on its surface, and therefore as a measure of the probable concentration of adsorbed oxygen. The amount of iodine absorption, also approximately proportional to the oxygen absorption, might be similarly explained.

Dennstedt and Bunz, however, considered the moisture content of the coal to be due to the hygroscopic nature of the ulmins in the coal, and thereby explained the higher moisture absorption of a coal after oxidation, a fact which has been noticed by Mahler (1913) and others. Mahler considered this water to be chemically combined, in the form of hydrates easily decomposable by heat.

Porter and Ralston (1916) found that although dry coal absorbs water with an evolution of heat, and a portion of this water is held tenaciously and possesses an abnormally low vapour pressure, it is unnecessary to assume chemical combination, since the phenomena exhibited can be completely explained on the assumption that coal is colloidal in nature and absorbs water as do other colloids.

*Oxygen Content.*—Dennstedt and Bunz found that the more inflammable coals contain most oxygen and little disposable hydrogen (*cf.* Richter (1870) ); they also considered that a certain amount of oxidation renders further oxidation easier.

Wheeler (1913, 1918) found a close parallel between the oxygen content of bituminous coals and their ease of ignition as denoted by their relative ignition temperatures.

As with the moisture content, the oxygen content was not regarded by Wheeler as necessarily directly influencing the ignition of the coal, but as indicating the presence to a greater or less extent of certain classes of oxygenated compounds in the coal, these oxygenated compounds being probably derived from the cellulosic degradation products of the original plants. Wheeler also pointed out that these oxygenated compounds may possibly, especially when more oxygen has been loosely

taken up, themselves attack the rest of the coal substance, giving rise to true ‘ self-heating.’

*Organic Constituents.*—The aim of many of the researches conducted on the spontaneous combustion of coal has been to discover what are the particular organic constituents of the coal-substance responsible for the reaction with oxygen. Undoubtedly the only hope of a complete solution of the problem lies in the proper recognition and knowledge of such constituents.

As might be expected from the slight knowledge at present possessed of the real nature of the compounds in coal, little success has so far attended these efforts. Between the work of one investigator and that of another, and even in the same work, there will be found anomalies, often apparently insurmountable. Whether these inconsistencies are apparent only, and are due merely to lack of knowledge, or whether they are real and due to wide variations between the coals used by different investigators, cannot yet be decided. If the latter, it would imply that there are profound differences between the chemical constituents of coals of apparently the same type, a suggestion which is in itself improbable.

Before giving a brief résumé of the present state of knowledge regarding the various constituents of coal, attention must be drawn to the gross differences evident in even a small sample of ordinary bituminous coal. The importance of this aspect of the subject is emphasised by the recent discrimination, in more detail than hitherto, of the macroscopically distinct ingredients of banded coal. Stopes (1919) has shown that ordinary ‘ banded ’ bituminous coals can be separated into, not only the long-recognised ‘ dull ’ and ‘ bright ’ bands, but into four distinct zones, which, though frequently merged together to form a complex mixture, yet can in other places be easily detected by the eye and even separated by hand in

a practically pure condition. These four zones show very considerable and very definite differences in their morphological structure as revealed by the microscope, and in their resistance to the various treatments used for their clarification before such examination. Such differences justify their recognition as distinct ingredients of the coal conglomerate. The four ingredients are named by Stopes:

*Fusain.*—The equivalent of 'mother of coal.'
*Durain.*—The equivalent of 'dull' hard coal ('Mattkohle').

| | |
|---|---|
| *Clarain.*—Banded bright lustre.<br>*Vitrain.*—Conchoidal fracture, brilliant appearance. | Together the equivalent of the previously noted 'bright' coal ('Glanzkohle'). |

In the Hamstead coal most particularly examined the durain is chiefly composed of large macrospores embedded thickly in an opaque matrix of granular particles. Clarain contains the greatest variety of recognisable plant structures, *e.g.* cuticles, spore exines, and 'resin bodies,' among which may be preserved plant stems and leaf-tissues; all are essentially translucent. Vitrain is remarkable for its very translucent and uniform structureless texture.

The differences between these ingredients were found by Tideswell and Wheeler (1919) to extend in some considerable degree to their chemical compositions, as indicated by analysis and by their reactivity towards various solvents and reagents (*see* Table VIII.), and also in their behaviour on distillation. The differences were evident in a regular and marked gradation of composition and of properties (chiefly a decrease in reactivity) in passing from vitrain, through clarain, to durain (excluding fusain as being markedly different in character from the remainder of the coal substance). This gradation of reactivity in all the methods of attack employed and evidenced especially in the products of distillation (*see*

TABLE VIII.

| | Vitrain. | Clarain. | Durain. | Fusain. |
|---|---|---|---|---|
| Density . . . . . | 1·290 | 1·280 | 1·395 | — |
| *Ultimate analysis.*—Per cent. on ash-free, dry coal : | | | | |
| Carbon . . . . . | 78·5 | 79·1 | 80·8 | 84·7 |
| Hydrogen . . . | 5·15 | 5·2 | 5·1 | 3·9 |
| Oxygen . . . . . | 13·9 | 13·4 | 11·8 | 9·7 |
| Nitrogen . . . | 1·33 | 1·28 | 1·3 | 1·05 |
| Sulphur . . . . . | 1·12 | 1·02 | 1·0 | 0·65 |
| *Proximate analysis :* | | | | |
| Moisture, per cent. . . | 12·6 | 10·2 | 6·5 | 3·9 |
| Ash, per cent. . . | 1·2 | 1·45 | 3·6 | 10·0 |
| Volatile matter, per cent. on ash-free, dry coal . . | 38·6 | 40·8 | 39·4 | 22·6 |
| *Extractions.*—Per cent. on ash-free, dry coal : | | | | |
| By pyridine . . . | 34·4 | 27·2 | 21·6 | 10·1 |
| By alcohol . . . | 6·6 | 5·7 | 3·1 | — |
| By chloroform . . | 2·85 | — | 2·4 | — |
| Pyridine extract soluble in chloroform, per cent. . . | 27·0 | 30·0 | 40·0 | — |
| Percentages of $\alpha$-, $\beta$-, and $\gamma$-compounds in the coal : | | | | |
| $\alpha$-Compounds . . . | 65·8 | 72·8 | 78·4 | — |
| $\beta$- ,, . . . . | 25·0 | 19·0 | 13·0 | — |
| $\gamma$- ,, . . . . | 9·2 | 8·2 | 8·6 | — |
| *Action of reagents.*—Per cent. on ash-free, dry coal : | | | | |
| Solubility in alcoholic potassium hydroxide : | | | | |
| (1) Hot . . . | 6·1 | 5·4 | 3·8 | — |
| (2) Cold . . . | 5·7 | 5·2 | 3·6 | — |
| Iodine absorption (permanent) : | | | | |
| N/10-aqueous iodine, in 24 hours . . . | 22·8 | 23·6 | 17·8 | 4·3 |
| Wijs's solution, in 6 hrs. | 67·9 | 63·2 | 51·3 | 4·3 |
| *Distillation.* — Gases evolved 0–600° C. c.c. per gram. . | 199 | 173 | 140 | 98 |

Fig. 1) suggests that the variation in composition between

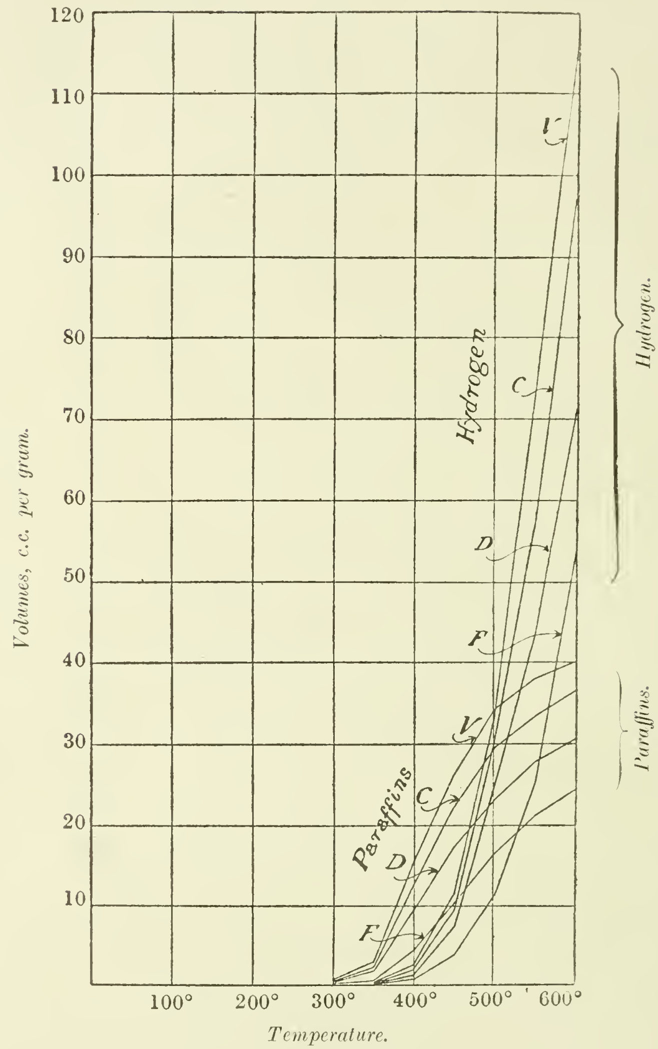



FIG. 1.

*Production of Hydrogen and of Paraffin Hydrocarbons from the four coals at temperatures rising to 100° C.*

vitrain, clarain, and durain does not lie essentially in any fundamental differences in the types of compounds of which

they are composed, or even in the relative proportions present of the usually recognised ($\alpha$-, $\beta$,- and $\gamma$-) coal constituent types, but that it is due to an admixture, for these three main coal ingredients, of approximately similar 'reactive' material with varying amounts of at present unknown 'inert' material.

Marked differences were found by Lessing (1920) in the behaviour of these coal ingredients towards coking, clarain and vitrain forming well-fused cokes, while durain was practically devoid of any coking value. Even greater dissimilarity was found in their ash-contents, durain giving a mainly insoluble ash consisting chiefly of an aluminium silicate of the approximate composition of clay substance, while clarain and vitrain give ashes probably representing the original plant ashes; though containing much less alumina than that of durain, the ratio $Al_2O_3/SiO_2$ in these ashes suggests their derivation from lycopodia. A connexion is suggested between the high magnesia content of clarain and the presence of stem and leaf tissue observed under the microscope.

Though these results do not appear to bear directly on the question of the spontaneous combustion of coal, yet when it is emphasised that all these distinct ingredients occur in most bituminous coals (though not in all cases so easily separable in a pure condition as from the Hamstead coal) it will be seen that their discrimination possesses very considerable importance, and is necessary, even apart from the question of any intrinsic variation in their ease of oxidation, in order to simplify as far as possible the working material. As would be expected from coals having such different compositions, the three main ingredients of the Hamstead coal show considerable variation in their oxidisability (Tideswell and Wheeler (1920) ).

The oxygen absorption curves at various temperatures are

shown in Figs. 2, 3, and 4. The general order of reactivity is followed, the bright ingredients, vitrain and clarain, showing greater liability to oxidise and to ignite than the dull durain. It is as yet uncertain whether this variation in ease of oxidation between the ingredients is directly due to their difference of composition or whether it is a secondary effect based on a difference in physical condition primarily caused

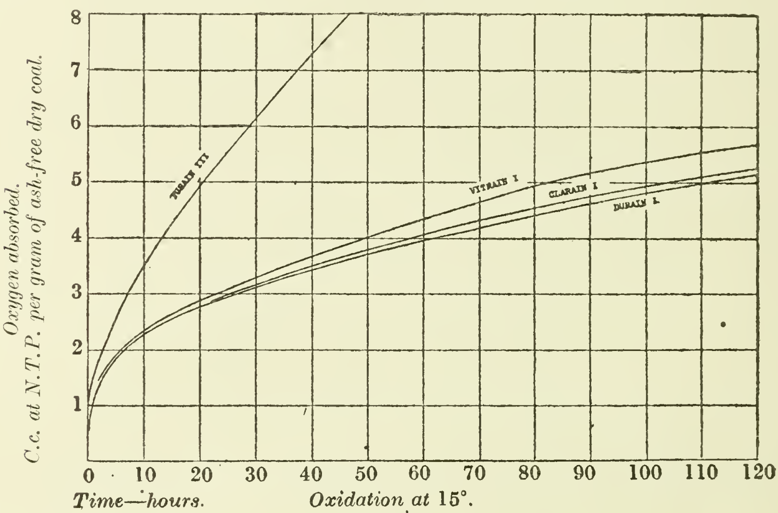



FIG. 2.

by this difference in chemical composition. The difference in ease of oxidation between these ingredients, though marked, is not so great as to warrant the suggestion that the bright portions of the Hamstead coal are primarily (and to the exclusion of the dull portions) responsible for its liability to spontaneous combustion.

It is preferable to consider separately the fourth ingredient of banded bituminous coals, fusain, on account both of the marked differences in chemical and physical natures between it and the rest of the coal, and of the growing belief amongst

practical men in its importance as a factor in the spontaneous combustion of coal (*see also* Sinnatt, Stern, and Bayley (1920)). The great difference in chemical nature between fusain and the bulk of the coal substance results from its formation by a particular process of aerial decay from certain portions only, the woody tissue and bark of the original plant life. Of equally great importance is its physical occurrence, the fibrous porous

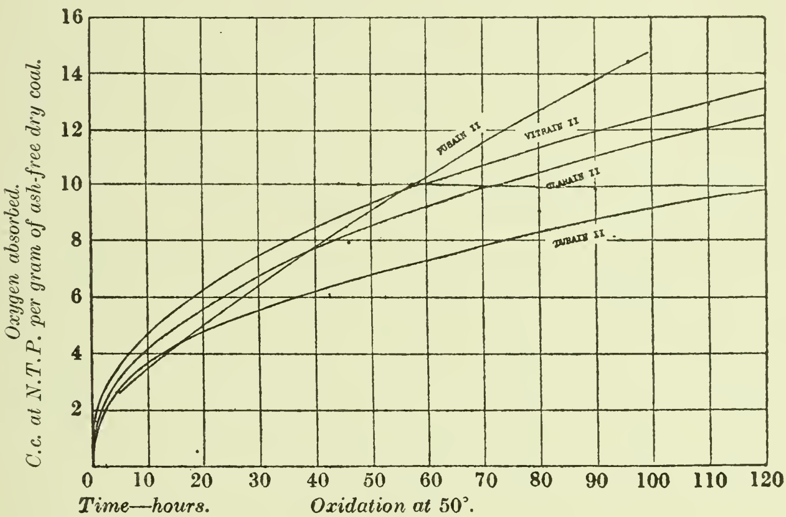



Fig. 3.

character of the fusain patches offering considerable opportunity to the attack of oxygen. Experimental evidence of the comparative susceptibility to oxidation of the fusain and of the main coal substance is as yet scanty, but points to the fusain having a much greater capacity for the absorption of oxygen than the rest of the coal at low temperatures (*see* Figs. 2 and 3).

Although it is improbable that fusain exerts a preponderating influence in determining the actual ignition of the coal after self-heating has begun, it is possible, therefore, that in

spite of its small usual content in the coal the rapid absorption of oxygen by fusain at low temperature may cause an initial rise in temperature sufficient to start the rapid oxidation of the more easily oxidisable (bright) portions of the surrounding coal.

To determine this question with certainty, and it is clearly one which demands settlement, further experiments on similar

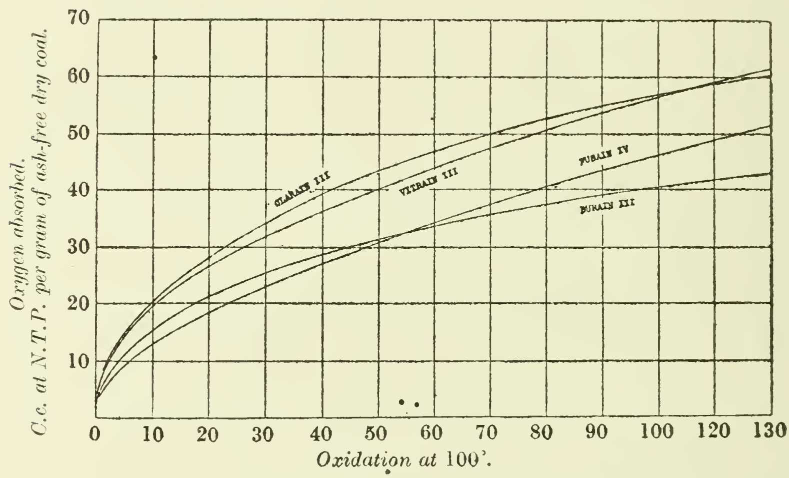



Fig. 4.

lines are being conducted, with a number of samples of fusain from widely different coals.

Returning to the question of the organic constituents of coal, our present state of knowledge of the composition of coal may be summed up in the belief that 'Coal is a conglomerate of morphologically organised plant tissues, natural plant substances devoid of morphological organisation (such, for instance, as "resin"), together with the degradation products of a portion of the plant tissue and cell contents comminuted, morphologically disorganised, or present in the form of varying members of the ulmin group. In our opinion, not only the

parts of plants " most resistant to decay " may be preserved entirely or almost unaltered, but also any parts, however delicate, which were sufficiently early enclosed by the aseptic mass resulting from a particular type of break-down of tissue, in which bacterial activity is inhibited and which has special preservative properties (such as are seen to-day in peat and tannins). Coal, therefore, contains compounds of a richly varied nature, many (perhaps the greater number) of which are not merged and resolved at haphazard through the coal substance, but cohere to maintain the very morphological structures in which they originally took rise.' (Stopes and Wheeler, 1918.)

Progress along the line suggested by these authors, the comparison or identification of specific portions of the coal substance with specific individuals of plant structure and their identification with definite chemical compositions, is necessarily slow, because of great complexity of the coal compounds. So far chemical researches have only succeeded in distinguishing in the coal conglomerate two main classes of compounds: the one apparently derived from the various celluloses which entered into the composition of the plants from which the coal was formed; the other of 'resinic' nature, presumably derived from the oils, gums, and resins of the original coal plants.

These two groups of compounds were originally suggested from the results of distillation of coals under varied conditions, but their presence has been definitely confirmed by the fairly good separation which can be made of these groups by means of solvents, more especially the successive use of pyridine and chloroform (or benzene).

These groups are termed (alpha- + beta-) compounds (which can be resolved into alpha- and beta-compounds, differing but little excepting as regards their solubility in pyridine) and

gamma-compounds. The chief characteristics of these groups are :

| $\alpha$- and $\beta$-*Compounds.* | $\gamma$-*Compounds.* |
|---|---|
| (1) Infusible. | Melt at 95–100° C. |
| (2) Yield but little liquid products (mainly phenols) on destructive distillation. | Yield about half their weight of liquid products on destructive distillation ; these are mainly paraffins, olefines, and naphthenes. |
| (3) Yield as gases on destructive distillation mainly hydrogen and the oxides of carbon. | Yield as gases on destructive distillation mainly the paraffin hydrocarbons. |

The molecules present in the $\alpha$- and $\beta$-compounds possess the furan structure (the basis of the cellulose molecule), while there are also present condensed molecules resembling the carbon molecule in structure. The compounds of the $\gamma$-group are formed of alkyl, naphthene, and unsaturated hydroaromatic radicles attached to larger and more complex groupings ; the oxygenated compounds in this group are chiefly oxides, probably cyclic in type. (Jones and Wheeler (1916).)

Bone (1918) has suggested a third type of coal constituents, the ‘ ammonia-yielding ’ nitrogenous constituents. While it is reasonable to expect the presence of such in the coal, derived from the protein matter of the coal-forming plants, so far there is no experimental evidence to show that these form a class separate from the other types and capable of being isolated.

As soon as the discovery of the high solubility of coal in pyridine was made by Bedson (1899), the association of the soluble portions of the coal with (1) the ‘ volatile matter,’ and (2) the portions responsible for the spontaneous combustion of the coal, became automatic (*see*, for example, Lewes, 1912). The first association after a considerable vogue has been finally broken ; this cannot as yet be said regarding the second. The term ‘ resinous,’ unfortunately applied to the portion soluble

in organic solvents, has perhaps been responsible for some confusion. Whilst the term is permissible when describing the general appearance and physical behaviour of the coal extracts, there is no evidence to show that their chemical nature resembles in any respect that of the true resins; or, indeed, that the small amount of true resinous matter present in most coals can be removed therefrom by solution in pyridine.

There is evidence that in the 'inflammability,' as distinct from the 'liability to self-heat,' of a coal, the soluble portions of the coal play an important part—for example, in the inflammability of clouds of coal-dust in air; but this is due chiefly to the ease with which they release inflammable gases on being heated. With the spontaneous combustion of coal quite different considerations arise. The responsible substances must be those which begin to oxidise so rapidly as to self-heat at temperatures either normal or so close to normal as to be reached as a result of some peculiar combination of the usual conditions.

Dennstedt and Bunz (1908) ascribed definitely the main heating effect to that part of the coal insoluble in organic solvents, which they regarded as the real coal substance probably formed from the original wood celluloses. This part contains the unsaturated compounds and yields ulmins on oxidation. However, the soluble portion of coal also apparently has some influence, for these authors found that in general the more inflammable coals contained a larger proportion soluble in pyridine, whilst oxidation of the coal decreased their solubility.

Nübling and Wanner (1915), using ignition methods similar to those of Dennstedt and Bunz, obtained very different results. Without exception the portion of the coal soluble in the various organic solvents used had a lower ignition temperature, whilst the residues had a higher ignition temperature, than the original

coal. As regards the unsaturated substances, these authors agreed with Dennstedt and Bunz that these are contained in the insoluble portions of the coal.

The close connexion between these unsaturated substances and the ease of oxidation of the coal had been suggested earlier by Fischer (1899), who attributed to these compounds almost the whole responsibility for the heating up of coal. Parr and Kressman (1910) also attributed the first stage of the heating up of coal to the addition of oxygen to these unsaturated compounds, apparently on the grounds that no carbon dioxide is formed during this action (other workers have, however, detected carbon dioxide; *see*, for example, Katz and Porter, 1917 B).

Returning to the consideration of the insoluble constituents, there is evidence from Parr and Hadley (1914) that the residue from their phenol extractions of coal absorbed oxygen more readily than the extract. Graham and Hill (1917) showed definitely that with Barnsley Softs coal an almost complete separation between the oxidisable and non-oxidisable constituents is made by extraction with pyridine. At temperatures up to 90° C. the residue showed an oxidation rate equal to that of the original coal, whilst the extract absorbed practically no oxygen. Whether this would hold at still higher temperatures, or whether the extract would inflame over some small range of temperature, remains to be determined. Such an occurrence might explain the results of Nübling and Wanner. Bone (1918) has suggested that the oxidation of coal is so complex that it is impossible to apply the results obtained by Graham and Hill for one coal, to coals as a whole. More general investigation would certainly be desirable.

The intimate connexion between the oxidation of a coal and the presence or formation of ulmins has been shown by many authors. These substances, variously termed ‘ humic acids ’ or

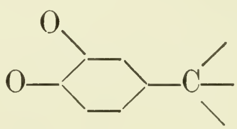
'ulmic acids,' have been investigated more fully than the other coal constituents and require a short description. A full account of them has been given by Stopes and Wheeler (1918).

The ulmins are generally amorphous brown products of vegetable decay, characterised by their solubility in dilute alkaline solutions, from which they are precipitated in brown flocks by acids. The name 'humic substances' has also been given to similar substances artificially formed, whilst the term 'ulmin' also includes very similar compounds which are not soluble in alkalies. The first recognition of these substances was made by Vauquelin (1797), who extracted them from elm bark with a solution of potassium carbonate; since then many such compounds have been described. They are present in rotted wood, in soils, and in large quantities in peat (where they are sometimes found in an almost pure condition, as 'Dopplerite'). Similar substances have been found in lignites and in small quantities in bituminous coals, but not in anthracites.

Analyses of these bodies have frequently been made. Dopplerite has been found to have a general composition varying between 51 to 58 per cent. carbon; 5 to 6 per cent. hydrogen; 34 to 42 per cent. oxygen, and 0·5 to 2 per cent. nitrogen, while very similar compositions have been found for ulmins from peat and from lignites. All these ulmins seem related if only from their origin; they are all apparently produced by the decay of cellulosic compounds. In this connexion may be mentioned the well-known formation of similar substances by the action of acids on sugars and on carbohydrates generally. The compounds formed (condensed polybasic anhydrides derived from the acid or alcohol resulting from the changed sugar—*see* Berthelot and André (1892)) possess all the usual characteristics of naturally occurring ulmins, with the exception that they

are nitrogen-free. Similar ulmins are formed by the fusion of charcoal, wood, or coal with potassium hydroxide.

Researches by Cross and Bevan (1880, 1881, 1882) and Hoppe-Seyler (1889) have shown that there is a direct constitutional relationship between the ulmins (whether artificial from cellulose or sugar, or natural from peat or coal) and the tannins, on the one hand, and on the other hand between the ulmins and the 'pseudo-carbons' obtainable from coal. The ulmins all yield protocatechuic acid on fusion with potassium hydroxide (Demel (1882); Hoppe-Seyler (1889); Roger and Vulquin (1908)), and therefore contain the grouping



which is present also in the lignone portion of lignocelluloses and in the tannins. Roger and Vulquin showed that the alcoholic properties of the celluloses were still preserved in the ulmins and also a secondary acetyl (—$CH_2$—CO—) constituent; further, that the unsaturated halogen-fixing components of lignocellulose were still present (*see also* Erdmann and Stolzenberg (1908)). Robertson, Irvine, and Dobson (1907) showed the presence in ulmins of the alkoxy groups (—$OCH_3$) of the original lignone complex. Recent work by Maillard (1912–1917) has shown that bodies resembling very closely the natural ulmins are formed by direct interaction at low temperatures between sugars and amino-acids (and also between carbohydrates in general and proteins and their decomposition products), and this may probably be the reaction responsible for the natural formation of ulmins. The disappearance of the ulmins, as one passes from the lignites to the anthracites, has led observers to the conclusion that the ulmins

are intermediate products in the formation of the coal substance (*e.g.* Boudouard (1911) ).

It is rather difficult to fix the precise place which the ulmins occupy in the process of the oxidation of coal. That they are a product of oxidation of the cellulosic portions of the coal is agreed by most workers, though Lewes (1912) considered the 'humus constituents' of a coal to be formed as a result of the oxidation of the 'resinic' constituents, which latter he believed to be mainly responsible for the spontaneous combustion of coal. Dennstedt and Bunz considered the ulmins to be the end products of the slow oxidation of coal, but at the same time considered a high ulmin content to indicate a high degree of inflammability. This is possibly explained by their contention that there exists in the slow oxidation of coals an intermediate stage of great oxidisability which the more inflammable coals have already reached. This has also been suggested by Wheeler.

The ready reactivity of the ulmins towards ozone has been proved by the work of Erdmann and Stolzenberg (1908), and possibly this reactivity shows itself in their ease of direct oxidation; or, as those authors suggest, the formation of ozone and its combination with the coal substance, especially with the ulmins, may proceed together.

It must not, of course, be understood that the ulmins produced by the direct oxidation of coal and lignite are identical in all respects with those previously existing in these substances, and which are a result of the natural processes of decay of the coal-forming materials. Although their general constitutions, as judged from their known behaviour, are very similar, yet, according to Boudouard (1908) and others, the former contain a considerably larger proportion of oxygen than the naturally occurring ulmins. It has not been possible to do otherwise than group together these ulmins of somewhat different origin,

but probably to their differences must be ascribed at least a little of the confusion which attends this branch of the subject.

Considering as a whole the researches reviewed on the relationship between the chemical constituents and the ease of oxidation of a coal, it will be seen that the general consensus of opinion amongst investigators is to place the onus for the spontaneous combustion of coal mainly, though not exclusively, on those parts of the coal substance which may be considered to be derived from the cellulosic portions of the original coal-forming materials ; that is, on those coal constituents resistant to solvent action and which have been designated by Wheeler and Stopes alpha- and beta-compounds.

The recent studies in the mechanism of the combustion of coal approach the question of the coal compounds responsible for spontaneous combustion from a different view-point. The very great similarity found between the processes of oxidation and of carbon points to the constituents which cause the absorption of oxygen (not necessarily, or even probably, those compounds which finally become oxidised) as being related in structure to carbon itself. Although all evidence is against the presence of ‘ free carbon ’ in coal, the presence of compounds of a similar structure, but still containing considerable proportions of oxygen and hydrogen, has been inferred from other considerations of a totally different nature.

Such compounds, which possibly include substances of the ulmin type, will find their source in the original celluloses and compound celluloses ; thus evidence from this point of view confirms the conclusions drawn from the chemical evidence, which on the whole places the responsibility for the spontaneous combustion of coal on those compounds derived from the cellulosic portions of the original coal-forming materials. Further and more precise definition of these dangerous constituents awaits further investigation. It is idle to hope for

much further progress from considerations involving the coal as a whole, while final success presupposes an intimate knowledge of each separate coal compound, such as is aimed at by the correlation of each microscopically distinct morphological structure with a definite chemical composition. In the meantime, work on the composition and reaction towards oxygen of the many distinct portions into which coal can be divided, either by mechanical means or by treatment with solvents and reagents, offers considerable hope of advancement towards a solution of this important question.

## PAPERS QUOTED IN THE TEXT.

To save repetition in numerous footnotes, the papers referred to in the text are here alphabetically arranged, so that full reference can be found by turning up here any author quoted in the preceding paper. Thus BEDSON, F. PHILLIPS (1899). Where an author publishes several papers they are arranged in order of date; two or more in the same year receive letters, thus, MAILLARD, L. C. (1912 A) or (1912 B).

PAGE

BEDSON, F. PHILLIPS (1899). 'Results of the Analysis of Samples of New Zealand Coal and Ambrite, and of Barbados Manjak.' *Trans. Fed. Inst. Min. Eng.*, vol. 16, pp. 388–390. Newcastle, 1899 . . 240

BEDSON, F. PHILLIPS (1913). 'First Report of the Departmental Committee on Spontaneous Combustion of Coal in Mines.' Minutes of Evidence, 1st to 7th days, February 12 to August 13, 1913, pp. 92–99. London, 1916. . . . . . . . . . 196

BERTHELOT, M., and ANDRÉ, G. (1892 A). 'Recherches sur les substances humiques.' *Ann. Chim. Phys.*, sér 6, vol. 25, pp. 364–403. Paris, 1892. . . . . . . . . . . . . 243

BERTHELOT, M., and ANDRÉ, G. (1892 B). 'Recherches calorimetrique sur l'acide humique derivé du sucre.' *Ann. Chim. Phys.*, sér. 6, vol. 25, pp. 403–420. Paris, 1892. . . . . . . . 243

PAGE

Berthelot, M., and André, G. (1892 c). 'Sur l'oxydation spontanée de l'acide humique et de la terre végétable.' *Ann. Chim. Phys.*, sér. 6, vol. 25, pp. 420–422. Paris, 1892. . . . . . . 243

Bone, W. A. (1918). 'Coal and its Scientific Uses.' *Monographs on Industrial Chemistry*, pp. xv, 491. 94 text figs. London, 1918. . . . . . . . . . . . 211, 240, 242

Boudouard, O. (1908). 'Sur les matières humiques des charbons.' *Compt. Rend. Acad. Sci.*, vol. 147, pp. 956–988. Paris, 1908. 188, 245

Boudouard, O. (1909 a). 'Action de l'air et des agents oxydants sur les charbons.' *Compt. Rend. Acad. Sci.*, vol. 148, pp. 284–286 and 348–351. Paris, 1909. . . . . . . . . 188

Boudouard, O. (1909 b). 'Étude sur les charbons et leur pouvoir cokéfiant.' *Rev. Métall.*, vol. 6, pp. 446–458. Paris, 1909. . . 188

Boudouard, O. (1911). 'Action des agents physiques et chimiques sur le bois, la tourbe, le lignite ; formation des charbons.' *Rev. Métall.*, vol. 8, pp. 38–46. Paris, 1911 . . . . 188, 245

Charpy, G., and Godchot, M. (1916). 'Sur l'oxydation des houilles.' *Compt. Rend. Acad. Sci.*, vol. 163, pp. 745–747. Paris, 1916. . 210

Cross, C. F., and Bevan, E. J. (1880). 'Chemistry of Bast Fibres.' *Journ. Chem. Soc.*, vol. 38, pp. 666–668. London, 1880. . . 244

Cross, C. F., and Bevan, E. J. (1881). 'Cellulose and Coal.' *Chem. News*, vol. 44, pp. 185–186. London, 1881. . . . . . 244

Cross, C. F., and Bevan, E. J. (1882 a). 'The Chemistry of Bast Fibres.' *Journ. Chem. Soc.*, vol. 41, pp. 90–110. London, 1882. . 244

Cross, C. F., and Bevan, E. J. (1882 b). 'On Pseudo-carbons.' *Phil. Mag.*, ser. 5, vol. 13, pp. 325–328. London, 1882. . . . 244

Demel, W. (1882). 'Über der Dopplerit von Aussee.' *Monat. Chem.*, vol. 3, pp. 763–769. Wien, 1882. . . . . . . 244

Demel, W. (1883) (Jahrgang, 1882). 'Über der Dopplerit von Aussee.' *Sitzungsber. K. Akad. Wiss*, vol. 86, abt. 2, pp. 872–878. Wien, 1883. . . . . . . . . . . . . 244

Dennstedt, M., and Bunz, R. (1908). 'Die Gefahren der Steinkohle.' 2. Die Selbstentzündlichkeit. *Zeits. angew. Chem.*, vol. 21, pp. 1825–1835. Berlin, 1908. . . 189, 224, 229, 230, 241, 245

Drakely, T. J. (1916). 'The Influence of Iron Pyrites on the Oxidation of Coal.' *Trans. Chem. Soc.*, vol. 109, pp. 723–733. London, 1916. . . . . . . . . . . . . 227

Drakely, T. J. (1917). 'The Liberation of Hydrogen Sulphide from Gob Fires in Coal Mines.' *Trans. Chem. Soc.*, vol. 111, pp. 853–863. London, 1917. . . . . . . . . . . . 228

PAGE

ERDMANN, E., and STOLZENBERG, H. (1908). 'Zur Frage der Selbstentzündung und Verwitterung aufgestapelter Braunkohle.' *Braunkohle*, 7, pp. 69–73; *Juni. Univ. Lab. f. angew. Chemie.* Sep. von. Vf. . . . . . . . . . . 186, 244, 245

See also *Chem. Zentr.*, 79, Jahrg., 1908, II, pp. 456–457. Berlin, 1908.

FAYOL, H. (1879). 'Études sur l'alteration et la combustion spontanée de la houille exposée à l'air.' *Bulletin, Soc. de l'Indust. Minérale*, second series, vol. 8, 3rd part. Dunod, Quai. des Augustins, 49. Paris, 1879. . . . . . 181, 221, 224

FISCHER, F. (1899). 'Über Lagerungsverluste und Selbstentzündung von Steinkohlen.' *Zeitsch. angew. Chem.*, vol. 33, pp. 787-790. Berlin, 1899. . . . . . . . . 186, 219, 242

GALLE, E. (1910). 'Über Selbstentzündung der Steinkohle.' *Centr. Bakt.*, 1910, 2, vol. 28, pp. 461–473. 10 text figs. . . . 216

GRAHAM, J. I. (1914). (*See also* WINMILL, T. F.) 'The Absorption of Oxygen by Coal.' Part V. *Trans. Inst. Min. Eng.*, 1914, vol. 48, pp. 521–534. London, 1914. . . . . . 201, 202, 225

GRAHAM, J. I. (1915). 'The Absorption of Oxygen by Coal.' Part VII. *Trans. Inst. Min. Eng.*, 1915, vol. 49, part i, pp. 35–43. London, 1915. . . . . . . . 202, 217, 219

GRAHAM, J. I. (1916 A). 'The Permeability of Coal to Air or Gas, and the Solubilities of Different Gases in Coal.' . . . . . 208

GRAHAM, J. I. (1916 B). 'The Absorption of Oxygen by Coal.' Part X. *Trans. Inst. Min. Eng.*, 1916, vol. 52, part iii, pp. 338–354. London, 1917. . . . . . . . . . . . 203

GRAHAM, J. I. (1919). 'The Permeability of Coal to Gases.' Part II. See *Colliery Guardian*, 1919, vol. 118, p. 1043. London, 1919. . 208

GRAHAM, J. I., and HILL (1917). 'The Oxidisable Constituents of Coal.' Part I. *Trans. Inst. Min. Eng.*, 1917, vol. 54, part iii, pp. 197–224. London, 1918. . . . . . . . . . 209, 242

HALDANE, J. S. (1917). 'The Spontaneous Firing of Coal.' *Trans. Inst. Min. Eng.*, 1917, vol. 53, part iv, p. 194. London, 1917. . 209

HALDANE, J. S., and MEACHAM, F. G. (1898). 'Observations on the Relation of Underground Temperature and Spontaneous Fires in the Coal to Oxidation and the Causes which favour it.' *Trans. Inst. Min. Eng.*, 1898, vol. 16, pp. 457–492, Plate I. Newcastle-on-Tyne, 1899. . . . . . . . . . 224, 225

HOPPE-SEYLER, F. (1889). 'Über Huminsubstanzen, ihre Entstehung und ihre Eigenschaften.' *Zeit. Physiol. Chem.*, vol. 13, pp. 66–121. Strassburg, 1889. . . . . . . . . . . 244

PAGE

Jones, D. T., and Wheeler, R. V. (1914 a). 'The Composition of Coal.' *Trans. Chem. Soc.*, vol. 105, pp. 140–151. London, 1914. . . 240

Jones, D. T., and Wheeler, R. V. (1914 b). 'The Composition of Coal.' Part II. *Trans. Chem. Soc.*, vol. 105, pp. 2562–2565. London, 1914. . . . . . . . . . . 240

Jones, D. T., and Wheeler, R. V. (1915). 'The Composition of Coal.' Part III. *Trans. Chem. Soc.*, vol. 107, pp. 1318–1324. London, 1915. . . . . . . . . . . 240

Katz, S. H., and Porter, H. C. (1917 a). 'Effect of Low-Temperature Oxidation on the Hydrogen in Coal and the Change in Weight of Coal on Drying.' U.S. Bureau of Mines, Tech. Paper 98. Washington, 1917. . . . . . . . . . . . 210

Katz, S. H., and Porter, H. C. (1917 b). 'Effects of Moisture on the Spontaneous Heating of Stored Coal.' U.S. Bureau of Mines, Tech. Paper 172. Washington, 1917. . . . 203, 210, 220, 242

Lamplough, F. E. E., and Hill, A. M. (1913). 'The Slow Combustion of Coal Dust and its Thermal Value.' *Trans. Inst. Min. Eng.*, 1913, vol. 45, p. 629. London, 1913. . . . . . . 204, 225

Lessing, R. (1920 a). 'The Behaviour of the Constituents of Banded Bituminous Coal on Coking; Studies in the Composition of Coal.' *Trans. Chem. Soc.*, vol. 117, pp. 247–256. London, 1920. . 212, 235

Lessing, R. (1920 b). 'The Mineral Constituents of Banded Bituminous Coal; Studies in the Composition of Coal.' *Trans. Chem. Soc.*, vol. 117, pp. 256–265. London, 1920. . . . 212, 235

Lewes, V. B. (1912). 'The Carbonisation of Coal,' pp. xiv, 315. 27 text figs. London, 1912 . . . . . . 228, 240, 245

Lomax, J. (1911). 'The Microscopical Examination of Coal and its Use in Determining the Inflammable Constituents Present Therein' (read Manchester Geol. and Mining Soc., 1911). *Trans. Inst. Min. Eng.*, vol. 42, part i, pp. 1–20, Plates I–XII. London, 1912. . 222

Lomax, J. (1914). 'Further Researches in the Microscopical Examination of Coal, especially in Relation to Spontaneous Combustion.' *Trans. Inst. Min. Eng.*, vol. 46, part iv, pp. 592–635. Plates VII–XII. London, 1914. . . . . . . . . 222

Mahler, P. (1892). 'Contribution à l'étude des combustibles,' pp. x, 94. Paris, 1892. . . . . . . . . . . . 186

Mahler, P. (1913). 'Expériences sur l'oxydation de la houille.' *Ann. Mines.*, ser. 11, vol. 4, pp. 163–198. Paris, 1913. 189, 202, 219, 230

Maillard, L. C. (1912 a). 'Action des Acides Aminés sur les sucres; formation des mélanoidines par voie methodique.' *Compt. Rend. Acad. Sci.*, vol. 154, pp. 66–68. Paris, 1912. . . . . . 244

PAGE

MAILLARD, L. C. (1912 B). 'Formation d'humus et de combustibles minéraux sans intervention de l'oxygène atmospherique, des micro-organismes des hautes températures, ou des fortes pressions.' *Compt. Rend. Acad. Sci.*, vol. 155, pp. 1554–1556. Paris, 1912. . 244

MAILLARD, L. C. (1913). 'Origine des bases cycliques du goudron de houille.' *Compt. Rend. Acad. Sci.*, vol. 157, pp. 850–852. Paris, 1913. . . . . . . . . . . . . . . 244

MAILLARD, L. C. (1916). 'Synthèse des matières humiques par action des acides aminés sur les sucres réducteurs.' *Ann. Chem. Phys.*, sér. 9, vol. 5, pp. 258–317. Paris, 1916. . . . . 244

MAILLARD, L. C. (1917). 'Identité des matières humiques de synthèse avec les matières humiques naturelles.' *Ann. Chim. Phys.*, sér. 9, vol. 7, pp. 113–152. Paris, 1917. . . . . . . 244

NÜBLING, R., and WANNER, H. (1915). 'Beitrag zur Selbstentzündlichkeit der Kohlen.' *J. Gasbeleuchtung*, vol. 58, pp. 515–518. München, 1915. . . . . . . . . 193, 241

PARR, S. W. (1917). 'Effects of Storage upon the Properties of Coal.' Illinois Univ. Eng. Exp. Stn., Bull. No. 97. Urbana, 1917. 196, 224

PARR, S. W., and BARKER, P. (1909). 'The Occluded Gases in Coal.' Illinois Univ. Eng. Exp. Stn., Bull. No. 32. Urbana, 1909. . . 195

PARR, S. W., and HADLEY, H. F. (1914). 'The Analysis of Coal with Phenol as a Solvent.' Illinois Univ. Eng. Exp. Stn., Bull. No. 76. Urbana, 1914. . . . . . . . . . . . 196, 242

PARR, S. W., HAMILTON, N. D., and WHEELER, W. F. (1907). 'The Weathering of Coal.' Illinois Univ. Eng. Exp. Stn., Bull. No. 17. Urbana, 1907. . . . . . . . . . . . . 195

PARR, S. W., and KRESSMAN, F. W. (1910). 'The Spontaneous Combustion of Coal.' Illiniois Univ. Eng. Exp. Stn., Bull. No. 46. Urbana, 1911. . . . . . . . . 195, 221, 224, 242

PARR, S. W., and WHEELER, W. F. (1909). 'The Weathering of Coal.' Illinois Univ. Eng. Exp. Stn., Bull. No. 38. Urbana, 1909. . . . . . . . . . . . . . 195

PARTINGTON, J. R. (1919). 'On the Oxidation of Coal.' *Chem. News*, 1919, vol. 118, pp. 50–51. London, 1919. . . . . . 213

PORTER, H. C., and RALSTON, O. C. (1914). 'A Study of the Oxidation of Coal.' U.S. Bureau of Mines., Tech. Paper 65, pp. 1–30. Washington, 1914. . . . . . . . . . . . 197

PORTER, H. C., and RALSTON, O. C. (1916). 'Some Properties of the Water in Coal.' U.S. Bureau of Mines, Tech. Paper 113, pp. 1–28. Washington, 1916. . . . . . . . . . . 230

PAGE

Potter, M. C. (1908). 'Bacteria as Agents in the Oxidation of Amorphous Carbon.' *Proc. Roy. Soc.*, 1908, B, vol. 80, pp. 239–259. London, 1908.. . . . . . . . . 215, 217

Rhead, T. F. E., and Wheeler, R. V. (1912 a). 'The Rate of Reduction of Carbon Dioxide by Carbon.' *Trans. Chem. Soc.*, vol. 101, pp. 831–845. London, 1912. . . . . . . . . 213

Rhead, T. F. E., and Wheeler, R. V. (1912 b). 'The Combustion of Carbon.' *Trans. Chem. Soc.*, vol. 101, pp. 846–856. London, 1912. . . . . . . . . . . . 213

Rhead, T. F. E., and Wheeler, R. V. (1913 a). 'The Mode of Combustion of Carbon.' *Trans. Chem. Soc.*, vol. 103, pp. 461–489. London, 1913. . . . . . . . . . . . 213

Rhead, T. F. E., and Wheeler, R. V. (1913 b). 'The Mode of Combustion of Carbon; Effect of drying the Oxygen.' *Trans. Chem. Soc.*, vol. 103, pp. 1210–1214. London, 1913. . . . . . 213

Richter, E. (1868). 'Ueber eine eigenthümliche Veränderung, welche die Steinkohle beim Erhitzen erleidet.' *Dingler's Polytechnisches Journal.*, vol. 190, pp. 398–401. Augsburg, 1868. . 184

Richter, E. (1869). 'Beiträge zur Kenntniss des Verhaltens der Kohle zum Sauerstoff.' *Dingler's Polytechnisches Journal*, vol. 193, pp. 51–61 and 264. Augsburg, 1869. . . . . 184, 223

Richter, E. (1870). 'Ueber die Veränderungen welche die Steinkohlen beim Lagern an der Luft erleiden.' *Dingler's Polytechnisches Journal*, vol. 195, pp. 315–331, 449–458; vol. 196, pp. 317–335. Augsburg, 1870. . [184, 202, 219, 221, 223, 229, 230

Robertson, R. A., Irvine, J. C., and Dobson, M. E. (1907). 'A Contribution to the Chemistry and Physiological Action of the Humic Acids.' *Biochem. Journ.*, vol. 2, pp. 458–480. Plates I–II. Liverpool, 1907. . . . . . . . . . . . 244

Roger, L., and Vulquin, E. (1908). 'Contribution à l'étude des matières humiques de l'ouate de tourbe.' *Compt. Rend. Acad. Sci.*, vol. 147, pp. 1404–1406. Paris, 1908. . . . . . 244

Russell, W. J. (1908). 'The Action of Resin and Allied Bodies on a Photographic Plate in the Dark.' *Proc. Roy. Soc.*, B., vol. 80, pp. 376–380. London, 1908. . . . . . . . . 188

Sinnatt, F. S., Stern, H., and Bayley, F. (1902). 'Coal Dust and Fusain.' Lancashire and Cheshire Coal Research Association, Bull. 5, pp. 1–19. Manchester, 1920. . . . . . . 237

Stopes, M. C. (1919). 'On Four Visible Ingredients in Banded Bituminous Coal; Studies in the Composition of Coal—I.' *Proc. Roy. Soc.*, 1919, B, vol. 90, p. 470. Plates 2. London, 1919. . . . . . . . . . . 211, 231

PAGE

Stopes, M. C., and Wheeler, R. V. (1918). 'Monograph on the Constitution of Coal.' (Based on a paper read before the London Section of the Soc. Chem. Ind.). *Dept. Sci. Ind. Research*, pp. 1–58. Plates I–III. H.M. Stationery Office. London, 1918. 239, 243

Threlfall, R. (1909). 'The Spontaneous Heating of Coal, particularly during Shipment.' *Journ. Soc. Chem. Ind.*, 1909., vol. 28, pp. 759–773. 11 text figs. London, 1909. . 186, 218, 221

Tideswell, F. V., and Wheeler, R. V. (1919 a). 'A Chemical Investigation of Banded Bituminous Coal; Studies in the Composition of Coal.' *Trans. Chem. Soc.*, 1919, vol. 115, pp. 619–636. London, 1919. . . . . . . . . 212, 232

Tideswell, F. V., and Wheeler, R. V. (1919 b). 'The Oxidation of Coal.' *Trans. Chem. Soc.*, 1919, vol. 115, pp. 895–902. London, 1919. . . . . . . . . . . . 213

Tideswell, F. V., and Wheeler, R. V. (1920). 'The Oxidation of the Ingredients of Banded Bituminous Coal; Studies in the Composition of Coal.' *Trans. Chem. Soc.*, vol. 117, pp. 794–801. London, 1920. . . . . . . . 212, 213, 235

Varrentrapp, F. (1865). 'Ueber die Bildung von Kohlensäure aus Braunkohlen beim Lagern an der Luft.' *Dingler's Polytechnisches Journal*, vol. 175, pp. 156–158, and vol. 178, pp. 379–385. Augsburg, 1865. . . . . . . . . . . . 184

Vauquelin, C. (1797). 'Sur une maladie des arbres qui attaque specialement l'orme et qui est analoque à une ulcère.' *Ann. Chim.*, vol. 21, pp. 39–47. Paris, 1797. . . . . . . . 243

Wheeler, R. V. (1913). 'First Report of the Departmental Committee on Spontaneous Combustion in Mines.' Minutes of Evidence, 1st to 7th days, February 12 to August 13, 1913, pp. 81–92. London, 1916. . . . . . . . . 196, 212, 230

Wheeler, R. V. (1918). 'The Oxidation and Ignition of Coal.' *Trans. Chem. Soc.*, 1918, vol. 113, pp. 945–955. . . 212, 230

Winmill, T. F. (*see also* Graham, J. I.) (1913). 'The Absorption of Oxygen.' Part I. *Trans. Inst. Min. Eng.*, 1913, vol. 46, part 3, pp. 563–591. London, 1914. . . . . . 188, 199, 225

Winmill, T. F. (1914). 'The Absorption of Oxygen by Coal.' Parts II, III, IV, and VI. *Trans. Inst. Min. Eng.*, 1914, vol. 48, pp. 503–520; 535–544. London, 1914. . 200, 202, 204, 217, 225

Winmill, T. F. (1916 a). 'The Absorption of Oxygen by Coal.' Parts VIII and IX. *Trans. Inst. Min. Eng.*, 1916, vol. 51, part 4, pp. 493–499, 510–531. London, 1916. . 198, 201, 205, 225, 229

Winmill, T. F. (1916 b). 'The Atmospheric Oxidation of Iron Pyrites.' *Trans. Inst. Min. Eng.*, 1916, vol. 51, part 4, pp. 500–509. London, 1916. . . . . . . . . . 225

## The Discussion

The President.

The PRESIDENT said he was sure they were all very grateful to Mr. Tideswell for his most excellent lecture and paper on the 'Constitution of Coal in relation to its Spontaneous Combustion.' They were greatly indebted to a gentleman of his high qualifications for having devoted so much of his time and attention to the work of research as to the qualities of coal and other substances used in the coal-mining industry. It was a labour of love, and the coal-mining industry generally must be greatly benefited by the researches he had made. Before proposing a very hearty vote of thanks to Mr. Tideswell for his valuable contribution, he would be very glad if any of the members would like to say a few words. He would call upon Principal George Knox.

Principal Geo. Knox.

Principal GEORGE KNOX said he could well support the words spoken by the President as to the good work done by Mr. Tideswell in the field of mining research. He had only seen a copy of his paper since coming here, and he was afraid that under the influence of their holiday the paper had not yet received the consideration from members which it ought to have had. He noticed one or two parts that were exceedingly interesting to the members of the Institute, particularly coming so soon after the paper contributed by his colleague, Mr. Illingworth. The subject of the paper divided itself into two parts. Firstly, in regard to spontaneous combustion underground. In some parts of South Staffordshire, where experiments had been carried on for many years in a very haphazard sort of way, quite different to the scientific and systematic method of Mr. Tideswell's experiments, it had been found that it was not the coal itself, but very fine shale associated with the coal, which was the chief cause of the

spontaneous ignition underground. The same opinion had been held in other quarters. In regard to spontaneous ignition of coal on the surface, they had had some instances in South Wales where this was attributed to the coal being tipped in far too large heaps. In discussing this matter with one of the largest exporters of coal, he pointed out that one difficulty they had always had in the storing of coal was that coals of mixed qualities, such as South Wales, and Scotch steam coals, &c., were found to be much more liable to spontaneous combustion than where the different coals were kept separate. In such cases the mixed coal when stored almost invariably ignited spontaneously. The same sort of thing happened in transport; in almost every case there was trouble before the voyage was completed. There were coals that could be safely handled and safely stored when kept separate, but when put together and stored under the same conditions produced this disastrous result. **Principal George Knox.**

Mr. TIDESWELL: With the same depth of storage? **Mr. Tideswell.**

Professor KNOX: Yes, under precisely the same conditions. It was a matter that was closely associated with the problem of heating and its cause. Once heating in coal was started, they found the same results very rapidly occurring. The trouble was to find exactly which constituents of coal produced the initial effect of heating. **Professor Knox.**

Mr. Tideswell quite justifiably referred to coal as a conglomerate of morphologically organised plant tissues, natural plant substances devoid of morphological organisation, together with the degradation products of plant tissue and cell contents, and if coal had always been studied as an ordinary sedimentary deposit, and not as something outside the pale of normal stratigraphy greater progress might have resulted in the study of this remarkable Rock.

Dr. Stopes had recently separated this coal conglomerate

Professor Knox.

into four distinct ingredients, *e.g.* 'Fusain' (Mother of coal), 'Durain' (chiefly dull spore coal), 'Clarain' (bright coal containing recognisable plant structures), and 'Vitrain' (bright bands of degradation products), microscopically structureless and translucent. This was a sub-division of great interest from both the geological and chemical points of view, but it was difficult at present to see to what use this could be applied commercially, as these ingredients were mixed up in most coal conglomerates in such finely divided quantities that their separation was impracticable.

At the School of Mines Mr. Illingworth had attacked this problem of the constitution of coal from a different view point and with considerable success. He had first dealt with coals having a wide range of volatility with a view to determining the nature of the constituents in coal producing coke-structure, and had shown (1) that the decomposition of coal at 450° C. results in the destruction of the pyridine-soluble constituents of the coal substance: (2) that in all probability the $\beta$ cellulosic substances are the first to decompose; (3) that there are two types of $\beta$ cellulosic and resinic compounds in coal, one of which is very unstable and the other comparatively stable.

Subsequently Mr. Illingworth continued his researches on a particular coal which (like all South Wales seams) varies in composition by loss of volatile products as it passes from East to West, and has demonstrated that this difference is due to the difference in unstable compounds which can be decomposed at 400° C. Further, he has shown that coals which could not be satisfactorily coked at high temperatures before the unstable compounds were decomposed can be coked after the unstable compounds have been decomposed.

The speaker, in enlarging upon the technical aspect of the questions involved, pointed out the differences in the constituents of South Wales coal and that of Staffordshire, and particularly

of Hamstead, and in conclusion he thanked Mr. Tideswell for the very great interest he had stirred up on the many important points raised by his paper and lecture, assuring him that he would appreciate the paper still more when he got home and had time to study it more closely. Professor Knox.

Mr. D. F. DAVIES said, in reference to the district he represented, that in investigating the cause of a gob fire in one of the pits, it was found that in parts of the seam in which the fire occurred there was a bank in the roof which contained a considerable amount of pyrites. It was found later, in washing this inferior compound, that even after a very wet day there was a considerable deposit of sulphur and fine particles of other substances. Unfortunately, there was a considerable amount of dust, which had spontaneously ignited, and they had to cut a dividing gutter to stop the spontaneous combustion. It was shown in this case that the large percentage of pyrites was an indirect factor, and this conclusion was borne out by the paper of Mr. Tideswell. Mr. D. F. Davies.

Mr. HEDLEY CLARK (Llwynpia), General Manager of the Cambrian Combine, on being called upon by the President, said he might add a lot to the discussion, but dinner was waiting (laughter). Moreover, his experience, unfortunately, had been mostly in geting out fires caused by coal ignition. Mr. Hedley Clark.

The PRESIDENT said in that case all he had now to do—and it was a great pleasure—was to propose a very hearty vote of thanks to Mr. Tideswell for his very excellent paper and lecture thereon. It was one which he could assure him would be studied very carefully by the mining community in the South Wales area. There was a great deal of valuable research work in it ; a great deal of matter for thought and deep study. He must say they depended almost entirely upon their chemists for their version of what coal and its constituents were. Coal had been exposed to analysis thousands The President.

The President. and thousands of times, and yet, according to the chemists, the analytical and chemical tests were by no means exhausted. He wished to include in the vote of thanks Mr. Timms for his work at the lantern, and also to state that an opportunity for a further consideration of the paper would be afforded at the Meeting in July at Cardiff.

The vote was carried with acclamation.

Mr. Tideswell. Mr. TIDESWELL, in responding, said he was grateful to the President and the members of the Institute for their cordial reception of his paper, and for the complimentary remarks that had been made. It was rather daring to venture the intrusion of so technical a paper on a holiday, but after such a reception he felt he was forgiven.

The proceedings then terminated.



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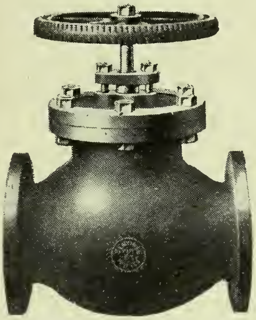

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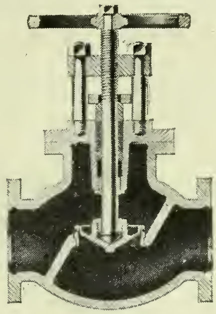

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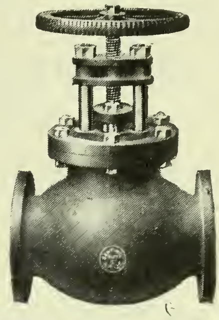

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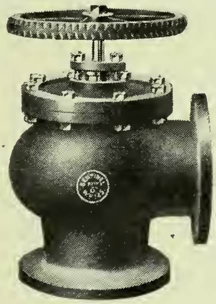

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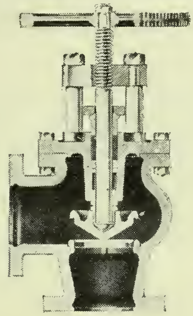

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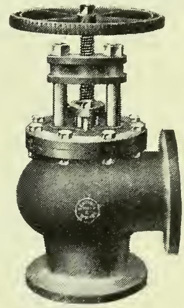

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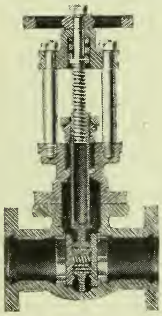

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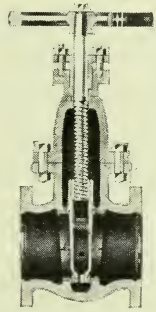

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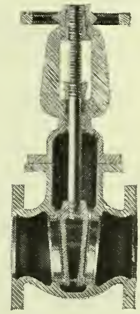

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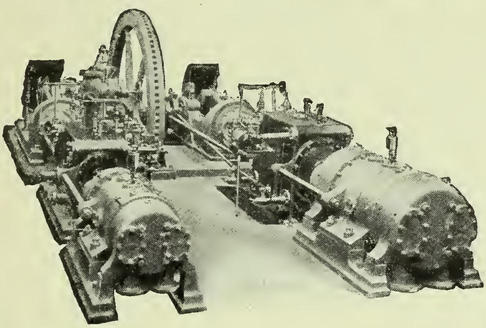

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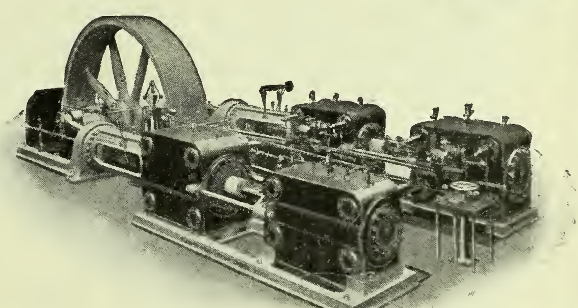

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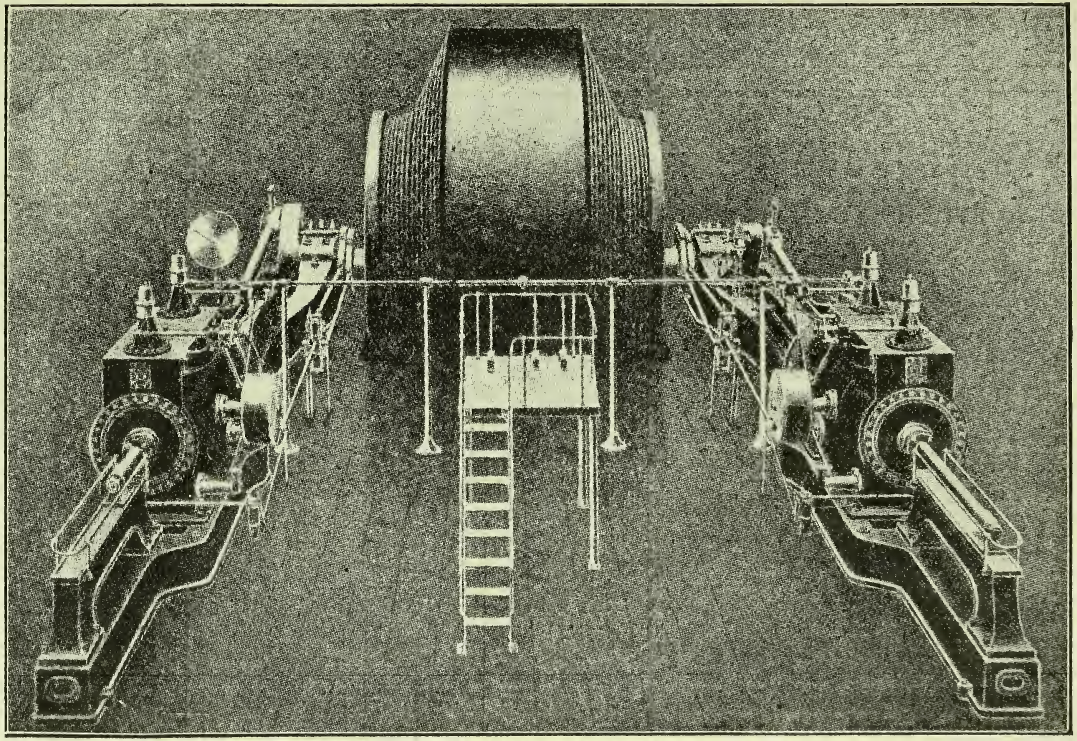

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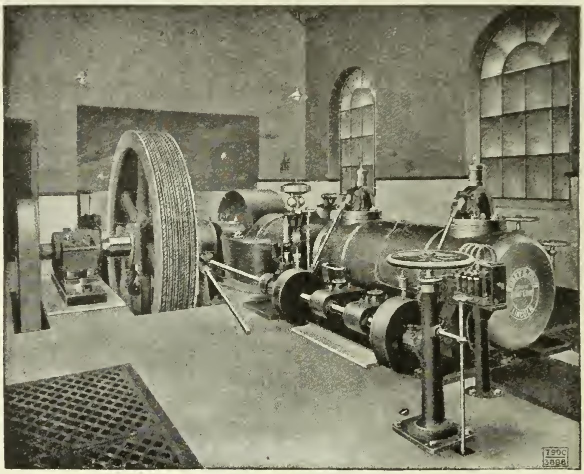

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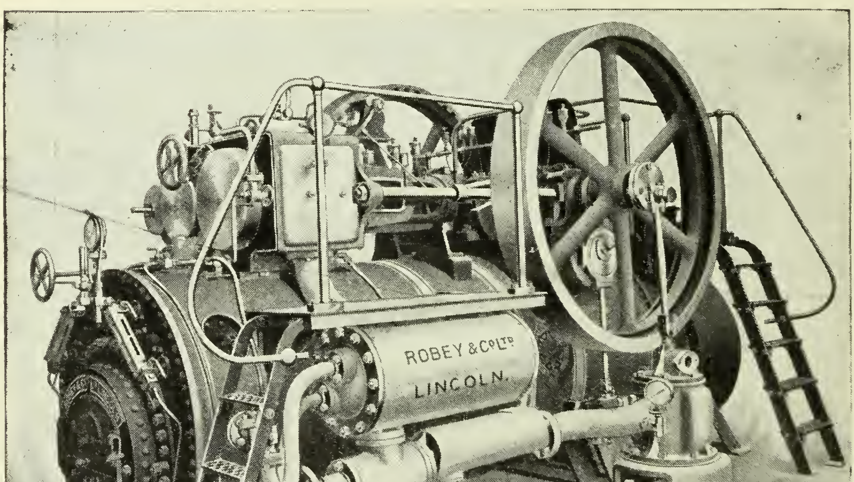


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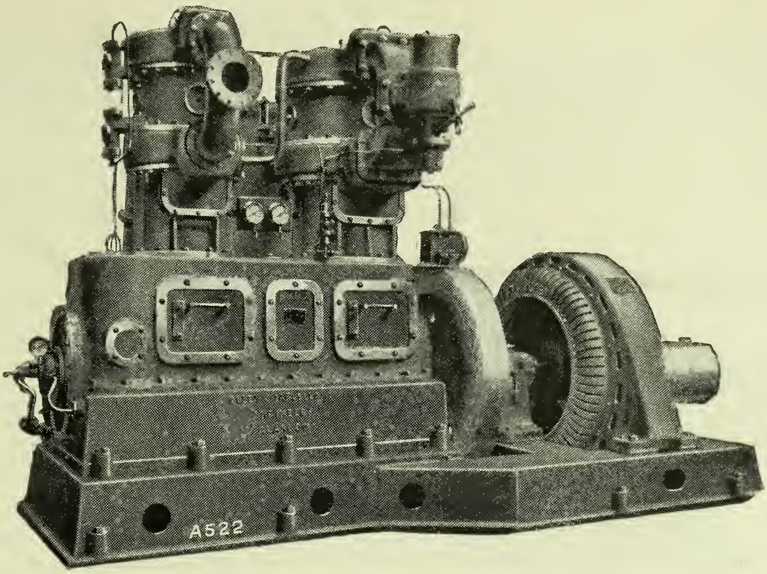
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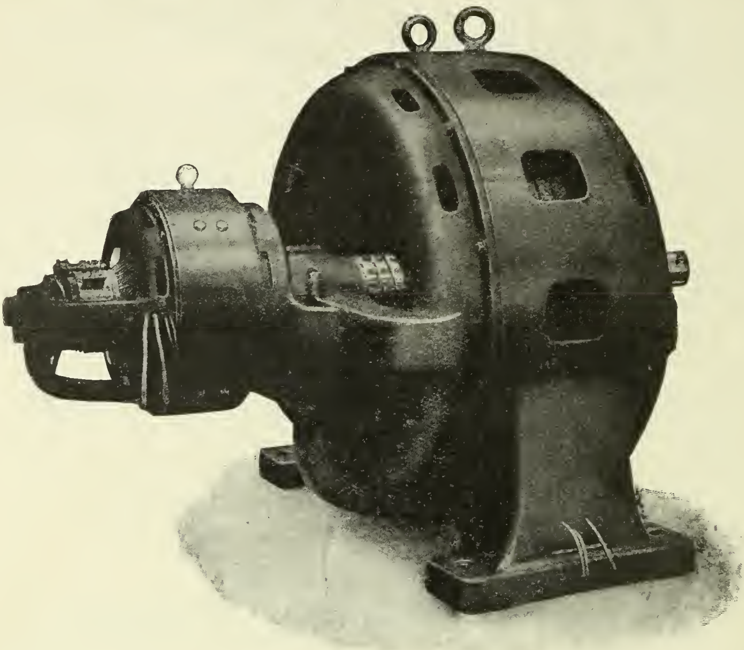

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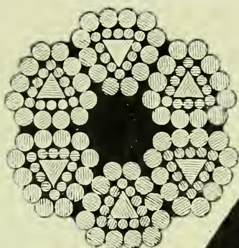

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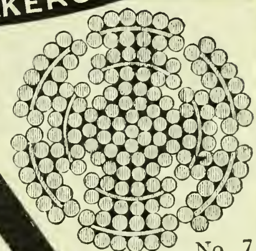

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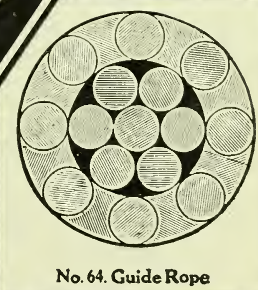

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EDITED BY THE SECRETARY




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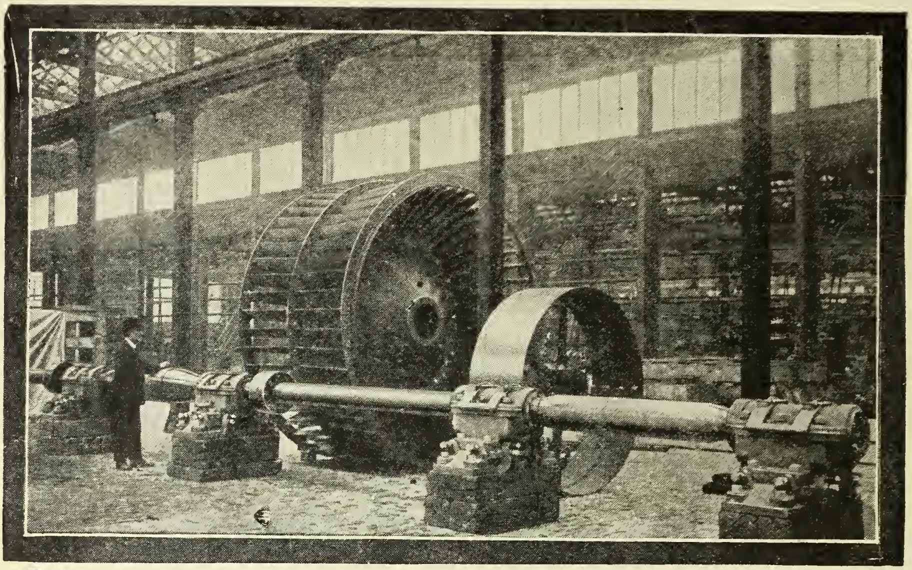

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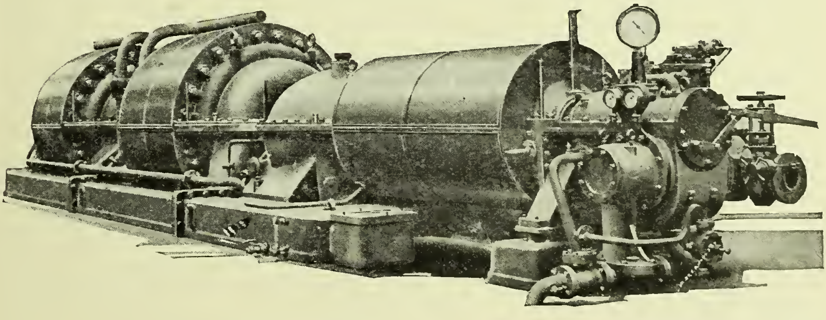

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| Menelaus, William, M.Inst.C.E. ... | 1857–58; 1864–65 ... | (Deceased) |
| Rogers, Ebenezer ... ... ... | 1858–59 ... ... | (Deceased) |
| Clark, William Southern ... ... | 1859–60 ... ... | (Deceased) |
| Brough, Lionel ... ... ... | 1860–61 ... ... | (Deceased) |
| Adams, William, A.M.Inst.C.E. ... | 1861–62 ... ... | (Deceased) |
| Evans, Thomas ... ... ... | 1862–63 ... ... | (Deceased) |
| Basset, Alexander, M.Inst.C.E. ... | 1863–64 ... ... | (Deceased) |
| Martin, George ... ... ... | 1865–66; 1866–67 ... | (Deceased) |
| Bedlington, Richard ... ... | 1867–68; 1868–69 ... | (Deceased) |
| Lewis, Sir William Thomas, Bart., M.Inst.C.E. (afterwards Lord Merthyr of Senghenydd), G.C.V.O. | 1869–70; 1870–71 & 1889–90; 1890–91 | (Deceased) |
| Steel, T. Dyne, M.Inst.C.E. ... | 1871–72; 1872–73 ... | (Deceased) |
| Brown, Thomas Forster, M.Inst.C.E. | 1873–74; 1874–75 & 1891–92; 1892–93 | (Deceased) |
| Brogden, James, F.G.S. ... ... | 1875–76; 1876–77 ... | (Deceased) |
| Laybourne, Richard ... ... | 1877–78; 1878–79 ... | (Deceased) |
| McMurtrie, James, F.G.S. ... | 1879–80; 1880–81 ... | (Deceased) |
| Williams, Edward, M.Inst.C.E. ... | 1881–82; 1882–83 ... | (Deceased) |
| Colquhoun, James ... ... ... | 1883–84; 1884–85 ... | (Deceased) |
| Hood, Archibald ... ... ... | 1885–86; 1886–87 ... | (Deceased) |
| Martin, Edward Pritchard, M.Inst. C.E. ... ... ... ... | 1887–88; 1888–89 ... | (Deceased) |
| Stevens, Arthur J., M.I.Mech.E. | 1893–94; 1894–95 | |
| Martin, Henry William, M.Inst.C.E. | 1895–96; 1896–97 | |
| Jordan, Henry Keyes, D.Sc., F.G.S. | 1897–98; 1898–99 | |
| Evens, Thomas, M.Inst.C.E. ... | 1899–00; 1900–01 | |
| Riches, T. Hurry, M.Inst.C.E. ... | 1901–02; 1902–03 ... | (Deceased) |
| Hann, Edmund Mills, M.Inst.C.E. | 1903–04; 1904–05 | |
| Deakin, Thos. Hedges, M.Inst.C.E. | 1905–06; 1906–07 | |
| Wight, William Dundas ... ... | 1907–08; 1908–09 & July 1911 to Dec. 1911 | |
| Rees, Ithel Treharne, M.Inst.C.E. | 1909–10; 1910 to July 1911 ... | (Deceased) |
| Galloway, W., D.Sc., F.G.S., F.I.D. | 1912 | |
| Elliott, A. C., D.Sc., M.Inst.C.E. | 1913 ... ... | (Deceased) |
| Atkinson, Sir W. N., LL.D. ... | 1913 (May 22 to Dec. 31, 1913) | |
| Wales, Henry T. ... ... ... | 1914 | |
| Griffiths, E. H., M.A., F.R.S. ... | 1915 | |
| Stewart, Wm. ... ... ... | 1916 | |
| Bramwell, Hugh, O.B.E. ... ... | 1917 | |
| Tallis, John Fox ... ... ... | 1918 | |
| Dawson, Edward, M.I.Mech.E. ... | 1919 | |

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*Past Presidents.*

| | Sessions |
|---|---|
| Stevens, Arthur J., M.I.Mech.E. ... ... | 1893–94, 1894–95. |
| Martin, Henry W., M.Inst.C.E. ... ... ... | 1895–96, 1896–97. |
| Jordan, Henry K., D.Sc., F.G.S.... ... ... | 1897–98, 1898–99. |
| Evens, Thomas, M.Inst.C.E. ... ... ... | 1899–00, 1900–01. |
| Hann, E. M., M.Inst.C.E. ... ... ... ... | 1903–04, 1904–05. |
| Deakin, T. H., M.Inst.C.E. ... ... ... | 1905–06, 1906–07. |
| Wight, Wm. D. ... ... ... ... ... | 1907–08, 1908–09 & July to Dec. 1911. |
| Galloway, W., D.Sc., F.G.S., F.I.D. ... ... | 1912. |
| Atkinson, Sir W. N., LL.D. ... ... ... | May22toDec.31,1913 |
| Wales, Henry T. ... ... ... ... ... | 1914. |
| Griffiths, E. H., M.A., F.R.S. ... ... ... | 1915. |
| Stewart, Wm. ... ... ... ... ... | 1916. |
| Bramwell, Hugh, O.B.E. ... ... ... | 1917. |
| Tallis, John Fox ... ... ... ... ... | 1918. |
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| O'Connor, W., F.G.S. ... ... ... ... | Argoed, near Newport. |
| Davison, J. W. ... ... ... ... ... | Pontypridd, |
| Llewelyn, Sir Leonard W., K.B.E. ... ... | Newport, Mon. |
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| Nicholas, Benjamin ... ... ... ... | Pontypool. |
| Thomas, Hubert Spence... ... ... ... | Whitchurch, Glam. |
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WAS AWARDED TO

MR. GEORGE DOUGLAS BUDGE.

PAPER, "STONE DUSTING IN STEAM COAL COLLIERIES."

# LEWIS PRIZE.

**Founded in 1895 by the late LORD MERTHYR of SENGHENYDD (Past-President), K.C.V.O., M.Inst.C.E., for the best Papers on subjects connected with Practical Mining and Practical Engineering, including Metallurgy.**

1898.—A First Prize was awarded to Mr. E. H. Thomas for his Paper on "Haulage," and a Second Prize to Mr. G. E. J. McMurtrie for his Paper on "Sinking."

1900.—A First Prize was awarded to Mr. S. A. Everett, and a Second Prize to Mr. E. H. Thomas, for Papers on "Colliery Surface Arrangements."

1901.—A Second Prize was awarded to Mr. Ralph Hawtrey, a Student, for his Paper "The Best and Most Economical System of Working Seams of Coal of Moderate Inclination in South Wales."

1904.—A First Prize was awarded to Mr. H. D. B. How, A.M.I.E.E., for his Paper "Coal Winding Machinery."

1905.—A First Prize was awarded to Mr. W. Waplington for his Paper "Description and Design of the Best Arrangements of Equipment of the Bottom, with a Radius of 400 yards, of a Pair of Pits to be Upcast and Downcast Respectively."

1906.—A Second Prize was awarded to Mr. George Roblings for his Paper "Separation (Sizing) and Washing of Coal."

1907.—A First Prize was awarded to Mr. Daniel Davies, and a Second Prize to Mr. Gath J. Fisher, for their Papers on "Pumping and Drainage," and also on "Sinking Shafts."

1908.—A First Prize was awarded to Mr. H. A. Staples, a Second Prize to Mr. George Roblings, and a Third Special Prize to Mr. M. D. Williams, for their Papers "As to the Best Methods of Working Seams of Coal in Steep Measures."

1909.—A First Prize was awarded to Mr. William Trimmer, and a Second Prize to Mr. C. W. Jordan, A.M.I.Mech.E., for their Papers on "General Lay-out and Equipment of a Complete Set of Engineering Shops for a Modern Colliery with an Output of about 2,000 tons per day."

1910.—A First Prize was awarded to Mr. George Roblings, and a Second Prize to Mr. Noah T. Williams, for their Papers on "Washing and Sorting of Small Coal."

1913.—Special Prize awarded Mr. Will Gregson for his Paper "The Most Approved Methods of Hauling the Coal from the Working Faces to the Pit Bottom."

1914.—Special Prizes awarded Messrs. J. Williams and S. R. Cound for their Papers on "How to Improve Welsh Tinplate Rolling-mill Practice."

1918.—A First Prize was awarded to Mr. W. T. Lane, and a Second to Mr. W. H. Casmey, for their Papers on "Fuel Economy in Power Production (or Utilisation of Waste Heat)."

1919.—A First Prize of £20 and a Second Prize of £10 were offered for a Paper on "Modern Metallurgical Furnace Practice," but no Paper was received.

## INSTITUTE SCHOLARSHIP IN ENGINEERING.

***Granted by the Council in 1904, and tenable for three years at the University College of South Wales and Monmouthshire.***

1904.—An EXHIBITION of £60, awarded to Mr. Ernest Clarke Stroud, Chatham.

1905-08.—A SCHOLARSHIP of £70 per annum, awarded to Mr. E.C. Stroud.

1908-11.—A SCHOLARSHIP of £70 per annum, awarded to Mr. Ivor Richard Cox, Cardiff.

1912.—An EXHIBITION of £60, awarded to Mr. Victor John French, Chatham.

1912-15.—A SCHOLARSHIP of £70 per annum, awarded to Mr. Victor John French.

1915-18.—A SCHOLARSHIP of £70 per annum, awarded to Mr. E. W. H. Knight, Devonport.

NOTE.—Mr. Knight was unable to take up the Scholarship he had won, and an honorarium of £10 was granted him by the Council, also a Certificate to the effect that he had won the Scholarship.

1919-21.—An EXHIBITION of £13 (plus a bonus of £15) per annum, awarded to Mr. E. G. Davies, Cardiff. (Won in 1915.)

1919-21.—A SCHOLARSHIP of £70 per annum, plus a bonus of £15 per annum, awarded to Mr. Myrddin David, County School, Porth, and

1919-20.—An EXHIBITION of £30 per annum for two years, awarded to Mr. J. Selwyn Caswell, Ebbw Vale.

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# NOTICES.



### PROCEEDINGS.

Back Numbers of the Proceedings have now been bound, from Vol. I. inclusive, in Volumes, in strong Duro-Flexile Cloth, and may be obtained from the Secretary at £1. 1s. per volume, or separate back numbers can be had at the various prices marked on the covers.

### CHANGE OF RESIDENCE.

The Secretary would be obliged by Members notifying to him any alteration in their addresses at the earliest date.

### INSTITUTE BUILDING.

The Institute, Park Place, Cardiff, is open for the use of Members on Week-days from 10 a.m. to 5 p.m.

The New Library is now open for the use of Members, and the technical journals and other periodicals will be found on the tables in that room, instead of in the Council Chamber.

# SPENCE THOMAS SCHOLARSHIP.

***(Founded in 1918 by Mr. H. Spence Thomas for the encouragement of the Members of the Associations of Students of the Institute.)***

The interest on £1,000 5 per cent. War Loan Stock shall be devoted to the Scholarship.

The Holder of the Scholarship must be a Member of one of the Students' Associations of the Institute, and must be a Student at one of the Colleges, Schools, or Institutions recognised as suitable by the Council of the Institute.

The Council of the Institute shall award the Scholarship upon Reports presented for its consideration by the Heads of any of the above Colleges, Schools, or Institutions, on the completion of one year's study by any student.

The College, School, or Institution shall present an annual report to the Council on the work and progress of the Scholar to whom the Scholarship shall have been awarded, and the Council retains the right of withholding or cancelling the Scholarship, if in its opinion the progress of the Scholar is unsatisfactory.

In the award of the Scholarship the professional knowledge and practical experience of the candidate shall be taken into consideration.

No candidate will be elected to the Scholarship until he has satisfied the Council that his physical condition is satisfactory.

The Scholarship shall be awarded for a term of one, two, or more years in the discretion of the Council. The Scholar to briefly report at the end of each year upon the work accomplished.

The Council reserves the right to withhold the Scholarship if no candidate of sufficient merit presents himself.

1919–1921. The Spence Thomas Scholarship of £50 per annum was awarded to Mr. William John Gilbert, Nantyglo, for a period of three years, tenable at the School of Mines, Treforest.

# ADVERTISEMENTS.



# CONTENTS.


No. 2. VOLUME XXXVI., issued January 21st, 1921, price 10s.

# PROCEEDINGS.

## Ordinary General Meeting, Cardiff, July 23, 1920.

The Ordinary General Meeting of the South Wales Institute of Engineers was held at the Institution, Cardiff, on Friday, July 23, 1920.

The chair was taken by the President, Mr. J. Dyer Lewis, H.M. Divisional Inspector of Mines.

The minutes of the Sixty-second Annual General Meeting of the Institute held on March 26, 1920, and of the Special General Meeting held on June 8, 1920, at Conishead Priory Hotel, were read and confirmed.

## Election of Members.

The following candidates for admission to the Institute were declared duly elected :

*As Members.*

| | |
|---|---|
| Allen, Charles Alexander . | Blackwood, Mon. |
| Brownlie, David . . . | Manchester. |
| Carter, George . . . | Llanharry, near Pontyclun. |
| Carter, Kenneth A. . . | Stoke-on-Trent. |
| Chrisp, George . . . | Port Talbot. |
| Cleverly, Arthur William . | Tredegar. |
| Ellis, Arthur . . . | Cardiff. |

| | |
|---|---|
| Farrant, John Henry . . | Porth, Glam. |
| Gavin, James . . . | Port Talbot. |
| Price, Clive Coleridge . | Penarth. |
| Reece, David . . . | Llanharan, Glam. |
| Roberts, T. W. Harcourt . | Haverfordwest. |
| Seymour, H. Williams . . | Pontyberem, Llanelly. |
| Simmons, Ernest Henry . | Bryncoch, near Neath. |
| Thomas, David Idwal . . | Tonypandy. |
| Thomas, Thomas Rees . . | Bryncoch. |
| Turnbull, John . . . | Cardiff. |

*As Associate Members.*

| | |
|---|---|
| Price, Glyndwr M. . . | Cardiff. |
| Smyth, W. Knight . . | Llandaff. |

*As Associates.*

| | |
|---|---|
| Bevan, Daniel . . . | Blaengwynfi, Glam. |
| Davies, Emrys . . . | Mardy, Glam. |
| Gandy, Herbert . . | Cardiff. |
| Hackett, John Henry . . | Newport, Mon. |
| Jones, Brinley Wyndham . | Porth, Glam. |
| Michelsen, Chas. Cuthbert . | Newport, I.W. |

*As Students.*

| | |
|---|---|
| Davies, John Hayton . . | Llanelly. |
| Garner, Philip Thomas . | Cardiff. |
| Griffiths, William Thomas, B.Sc. | Cardiff. |
| Martyn, James Vivian, B.A. . | Porth, Glam. |
| Morgan, William Marsh . | Mumbles. |
| Thomas, Montague . . | Pontypridd. |
| Wood, William Emlyn . . | Pontypridd. |

## Admission of New Members.

The following gentlemen, who had been previously elected, signed the Roll Book and were admitted to the Institute:

*As Members.*

| | |
|---|---|
| Hughes, Morris | Cardiff. |
| Jeffreys, H. | Cardiff. |
| Price, Clive Coleridge | Penarth. |
| Reece, David | Llanharan. |
| Simmons, E. H. | Bryncoch. |
| Thomas, T. R. | Bryncoch. |
| Turnbull, John | Cardiff. |

*As Associate Member.*

| | |
|---|---|
| Edwards, H. J. | Swansea. |

## Lewis Prizes, 1920.

The Council made it known that the subject selected for Lewis Prizes this year was—'Causes of Subsidences and the Best Safeguards for their Prevention.'

## The Single-Field Cascade Machine.

By L. J. Hunt, M.Inst.C.E., M.I.E.E.

(Paper, *vide* Proceedings Vol. XXXV., No. 2, p. 309.
Discussion, *vide* Proceedings, Vol. XXXVI., No. 1.)

No further comments being forthcoming on this paper, the President announced the close of the discussion, and thanked Mr. Hunt for his contribution. The President.

## Mining Leases.

By Hugh M. Ingledew.

(Paper, *vide* Proceedings, Vol. XXXVI., No 1.)

Mr. Ingledew.

Mr. Ingledew, reviewing the discussion, said Mr. Westgarth Brown had raised the important question whether it was in the interests of the community that a man should lease all the seams or whether these seams should be worked under different leases or lessees. There was doubtless a temptation to the man leasing all the seams under one lease to work the coal that suited him best and sold best in the market; but this was a matter upon which his hearers were more capable of pronouncing a judgment than he was. When members discussed his paper in its first form it was very properly pointed out that he had omitted reference to coal consumption at the colliery in dealing with royalties. He had inserted the following paragraph:

> 'The lessee should always be granted an allowance free of royalty in respect of colliery consumption. The more convenient practice is to grant a fixed percentage of the output up to 5 per cent., and in very special cases even over this figure. Where the allowance is on actual consumption it is usual to provide that a proportion of the coal used for power for adjoining minerals shall be debited to those minerals.'

Whilst on the subject of royalties he might state that in the 'Proceedings' he had corrected two errors that got into the advance proof of his paper, circulated at the previous meeting, when it was discussed. In the advance proof it was stated that 'a common royalty was 8*d.* on large coal and 4*d.* on small, which is equivalent to $7\frac{1}{3}d.$' This figure should be '$6\frac{2}{3}d.$,' as it now appeared correctly in the 'Proceedings.'

Again, in the next paragraph, referring to the old royalty based upon the long ton of 2520 lb., the words 'one-third' should, of course, be 'one-ninth.' This was also corrected in the 'Proceedings.' Members would also probably note (on pages 149–150 'Proceedings,' and page 25 advance proof) that he had made other points clearer. The paragraph beginning 'In the case of a wilful trespass' now read (as in the 'Proceedings'): Mr. Ingledew.

> 'In the case of a wilful trespass, the damages are assessed on what is known in the Chancery Court as the "harsher rule," that is to say, the trespasser has to pay the value of the coal at the pit bank less only the cost of bringing the coal to bank, the cost of working being disallowed. . . .
>
> 'It will be seen, therefore, that in case of a deliberate trespass the trespasser is fined the whole of the cost of severing the coal, that being the illegal act, but is allowed the cost of bringing it to the pit top, and the general experience of the cost of colliery working shows that the cost of severance is a serious matter, involving a minute examination of the cost of working, which was fully inquired into in Phillips *v.* Hombray, 1871, L.R. 6 Ch. App. 770.'

Continuing, Mr. Ingledew said Mr. Westgarth Brown had called attention to his remark, on the subject of subsidence, that 40 yards was based on an assumed depth of 200 yards to the minerals, and asked if he had an authority for the statement. He could not point to any authority, but in dealing with railway matters he had always understood this to be the case. It had been handed down to him as a tradition as it were, but he did not know of anything in any Act of Parliament, or any decision of the Courts on the point. On the question of trespass, he was asked by Mr. Morris when the

Mr. Ingledew. Statute of Limitations began to operate. He had not been able to find any direct authority on the point whether the Statute commenced to run from the date of the actual trespass or the date of discovery; but it seemed to him from the common-sense point of view, from the point of view of ordinary principles, that a man could not be bound by the Statute of Limitations unless, and until, he either knew of the trespass or ought to have known if he kept his plans properly and practised good mining. He had in mind the case of a trespass which took place about two miles from the nearest workings, and the owner had no opportunity of knowing or finding out that a trespass had occurred. He could not conceive in such a case as this that the Statute of Limitations could possibly run against the owner or lessee from the date of the actual trespass.

The President. The PRESIDENT said the Institute was greatly indebted to Mr. Ingledew for his paper, which reviewed different points of importance in mining leases in a manner to be easily grasped by the lay mind, and he had much pleasure in moving a vote of thanks to its author. (Applause.)

The discussion was closed.

## The Constitution of Coal in Relation to its Spontaneous Combustion.

BY F. V. TIDESWELL, M.SC.

(PAPER, *vide* PROCEEDINGS, Vol. XXXVI., No. 1, p. 181.)

Discussion was resumed on this paper.

Mr. Westgarth Forster Brown. MR. WESTGARTH FORSTER BROWN said he was afraid he was not a chemist, but there were one or two points to which he should like to draw attention. In the first place, he would

like to endorse what the President said at a previous meeting as to the value of the paper, because not only did Mr. Tideswell give them the benefit of the knowledge he had himself acquired but he brought members into touch with all recent information upon the subject. The impression one got from reading the various conclusions arrived at by the different investigators was that they could not hope to fix upon one invariable cause of the spontaneous combustion of coal, because evidently spontaneous combustion occurred under varying circumstances and the chemical actions were very complex. While the investigations seemed to be very valuable from the point of view of telling them of conditions under which the spontaneous combustion of coal took place, they did not tell them the initial cause; and until they knew that he did not think they would arrive at a means of preventing spontaneous combustion where the conditions were favourable to it. If one tried to explain to oneself what was meant by chemical action and electricity and heat, and so on, one came to one conclusion, namely, that they indicated that the molecules and atoms in the substances involved were out of equilibrium with something. If he were asked to suggest what that something was he should say that it was the forces which controlled the axial rotation of the earth in space. So long as molecules and atoms were in equilibrium with these forces they were neutral, and there were no phenomena, but directly that equilibrium was upset—and he imagined that all these molecules and atoms were rotating in the same way as the earth—they got phenomena of electricity and chemical action. He did not know that the paper actually said so, but there was a suggestion that the absorption of oxygen might be a cause of spontaneous combustion. Presumably absorption of oxygen was a chemical action itself; and if his argument was right, it could not be the initial cause. There must be something to throw the molecules and atoms out of Mr. Westgarth Forster Brown.

Mr. Westgarth Forster Brown.

equilibrium to start with. In two cases that had come under his notice he was inclined to say that friction had something to do with it. At one colliery a seam 8 feet thick was being worked by board-and-pillar method, pillars being left 20 yards square, increasing to 25 yards and up to 33 yards square. This went on for many years without any fire. Then the management commenced to work a seam 35 yards below; and in the pillars overlying the area being worked in the lower seam fires broke out, and in no other part of the colliery. The working of the lower seam was stopped and the fires ceased except in the area that was shut off. The other case to which he had referred was in another coalfield. A thick seam was worked for twenty years on the board-and-pillar system without any fire. Then—as in the previous instance—the management began to work a lower seam, when fire broke out in the pillars overlying that particular area. It would seem as if some movement, some grinding action, was produced on the pillars which started spontaneous combustion. It had occurred to his mind, seeing that the coals in both cases carried percentages of pyrites and combined moisture, and seeing that sulphur by itself was probably one of the most easily electrified substances and its molecules were easily thrown out of equilibrium—whether this was not the initial cause of the spontaneous combustion in those two instances. If they took the rolling of a ship they had the same thing. The rolling of a ship might produce the friction necessary to upset the equilibrium of the molecules and atoms; but, of course, friction could not be the cause in all cases. He was afraid he could not suggest any other initial cause unless it was bacteria—supposing bacteria were a living activity and not a chemical activity. His feeling about spontaneous combustion was that they had to leave the realm of chemistry for that of physics to ascertain the initial cause.

Mr. W. O'Connor said Mr. Westgarth Brown's theory was interesting, but it did not appear to furnish an explanation of spontaneous combustion in small coal tips. He recalled the case of a large heap of small coal at the top of the pit in which fire occurred in at least a dozen places. For some weeks before the flames were seen there would be a slight mist or vapour hanging upon the heap which could be discerned half a mile off; and the peculiar thing was that at the particular parts of the tip where the haze had been noticed fires broke out subsequently. Later on the fires ceased to occur; so that it would appear as if the ignition was associated with coal newly put out from the face, and that after a certain period of exposure spontaneous combination ceased. **Mr. W. O'Connor.**

Mr. W. D. Woolley said probably Mr. O'Connor referred to pit heaps belonging to his (the speaker's) company. At each of two collieries, situate two miles apart, a big heap of dry smalls accumulated at a time when small coal was a drug on the market. At one heap spontaneous combustion occurred to such an extent that the whole heap had to be removed, while the other tip was not affected, although both consisted of steam coal smalls apparently of much the same volatiles. The only difference between the heaps was that the one which was not affected was placed upon the solid soil, while the other was dumped upon an old tip; and his theory was that air got through the latter heap from the base and produced spontaneous combustion. **Mr. W. D. Woolley.**

The President: What was the height of the heap? **The President.**

Mr. Woolley: About 40 feet at the highest point. They were both much about the same height. There would be about 30,000 tons in each heap. **Mr. Woolley.**

Mr. J. W. Hutchinson said he had had experience in stacking large heaps of gas coal when in Lancashire—the stacks in some cases amounting to 40,000 tons of coal; the coal **Mr. J. W. Hutchinson.**

Mr. J. W. Hutchinson.

being stacked in the summer ready for the winter requirements. Although there were no signs of spontaneous combustion in these particular seams underground, yet the coal had to be very carefully watched when stacked on the surface, otherwise the whole heap would have got on fire. Much depended on the thickness of the heap. If it was kept to a certain height only, and ventilated with pipes, &c., there was no trouble. With regard to Mr. Brown's theory that fires occurred in pillars, he (Mr. Hutchinson) was inclined to think they took place in the goaf, and that they were due to friction at those particular parts, caused by the weight and squeeze of the overlying strata.

Mr. Westgarth Brown.

Mr. Westgarth Brown said in one case the fire occurred in the base of the pillars after they had been standing for some years. In one part the pillar was on a soft bottom, and here there was no fire; in the other case, the bottom was hard. The floors in both cases were analysed, and there was no comparison between the two analyses. The floor where the fire took place carried 6·98 of sulphur and a high percentage of combined moisture, whereas in the other case the sulphur was 0·2, or something of that sort, and the moisture was very low. The analyst said they were not the same constituents at all; yet they came from underneath the same seam. The fires took place in the pillars themselves.

Mr. Henry W. Martin.

Mr. Henry W. Martin said some fifty years ago he was working a colliery that was partly under the sea. The seam was 10 feet thick, and was worked by board and pillar. Large pillars were left; but he never found that fires originated in the pillars themselves. Above the seam of coal, just under the roof, was a small clod with iron pyrites in it, and whenever there was a fall of rubbish this stuff almost invariably fired. At one time the fire spread so rapidly that they were obliged to flood the mine—an extensive one. A 6-inch syphon pipe was put into the sea, and water let into the mine,

which after putting out the fire was afterwards pumped out. Soon after another fire occurred in the bottom of the workings, and they had to flood the mine a second time. As soon as ever rubbish fell with this stuff in it, a fire started and did damage. The place had to be kept absolutely clean, and pipes had to be laid through the mine so as to get a force of water upon any point at any moment. He did not know whether this reminiscence of many years ago was of interest to members. (Applause.) **Mr. Henry W. Martin.**

Mr. W. H. Reynolds said Mr. Brown's allusion to the rolling of a ship when on the question of friction as a possible cause of the spontaneous combustion of coal heaps reminded him, as a former sea-going engineer, that there were never in his experience fires in the bunkers when the coal was British, but fires were frequent with Japanese and Chinese bunker coals. The peculiar thing was, as touching upon Mr. Brown's illustration of the rolling of a ship, that these fires did not occur in rough weather, but always when the passage was fine. This spontaneous combustion was attributed, at the time, to the fact that almost invariably the Japanese and Chinese coal—especially the former—was shipped in a wet condition, and that the bunkers were in proximity to the boilers. **Mr. W. H. Reynolds.**

Mr. Henry W. Martin: Might I say that the colliery I spoke of was a Japanese colliery? (Laughter.) **Mr. Henry W. Martin.**

The President said this matter of spontaneous combustion was certainly a complex subject. Mr. Reynolds had referred to bunker coal. In the west of Glamorgan there were certain seams of coal which were of such a character that when probably some 200 miles out at sea from the port of shipment they would get on fire if the coal had been sent dry from the colliery, but if it had been thoroughly damped in the wagons no spontaneous combustion took place. **The President.**

A Member: I should like to see the analysis. **A Member.**

The President. The PRESIDENT said the underground fire did not originate with the coal itself. There were four or five beds of coal, running to a total of 2 feet 6 inches and 3 feet in thickness, and intervening between these small beds were bits of shale. In working longwall, some of the beds were ripped and placed in the gob 50 or 60 yards from the face. This gob got on fire, not from the main seam, but from the various little beds that were placed underneath the gob.

Mr. David E. Roberts. Mr. DAVID E. ROBERTS said people who used powdered fuel a good deal ought to be able to give useful information about the spontaneous combustion of coal. Ten or fifteen years ago he went to America to investigate the uses of powdered coal at works there. The practice was to have a small hopper in front of each furnace using powdered fuel, conveyors bringing the fuel from the mill to the hopper. The latter was conical in shape and about 2-tons capacity. However tightly these hoppers had been caulked, it was generally found every Monday morning, after the week-end shut-down, that the fuel in the point of the hopper at the outlet to the furnace was on fire, and some 18 inches of the hopper had to be scraped out before a proper start could be made. This firing was attributed to moisture and air leakage through the outlet valve of the hopper.

Dr. S. Wolff. Dr. S. WOLFF said it might be possible that under favourable conditions changes might take place and form inflammable gases which became ignited. By a continual alteration and transformation of the elements of coal certain gases might develop which would tend to ignite under certain conditions. He thought the question of ventilation had an important bearing on spontaneous combustion. Lack of ventilation would make it impossible for the gases to get away, and these under certain conditions would become ignited. It would be most interesting to try to collect and analyse gases from a coal heap, which is specially liable to spontaneous combustion.

The discussion was closed.

## Notes on a New Type of Colliery Tram.

BY W. D. WOOLLEY.

(PAPER, *vide* PROCEEDINGS, VOL. XXXVI., NO. 1.)

The PRESIDENT said the next subject for discussion was Mr. Woolley's paper on colliery trams. Perhaps Mr. Woolley had something more to say. **The President.**

Mr. WOOLLEY stated that he had not much to say to-day. The 'Notes' he had written were put forward mainly with the object of evoking comments and criticism, and eliciting views of members upon an important matter to all engaged in mining. Since he wrote the paper he had a good deal more experience of the tram described. Colliery officials were divided in opinion whether the tram in use should be of that type, or consist of a box type carried on a good substantial frame. He was still carrying on experiments. Members had probably seen the development of the 'clip' tram of the Sheffield district. He had half a dozen tram bodies sent him, which were put on frames of the type described in the 'Notes.' So far they had proved very successful. **Mr. Woolley.**

The PRESIDENT said it was necessary to point out that the South Wales colliery trams had other uses besides carrying coal from the face to the screening plant on the surface. He did not think he would be far wrong in stating that they conveyed as much rubbish as coal in the course of twelve months. The large quantity of rubbish yielded in the constant repairing and re-opening of the main haulage roadways and returns had to be transported either to the surface or to convenient places below ground in order to stow the coal faces and abandoned roadways. The rough usage which trams had to undergo while large stones were being loaded up was far greater than when they were employed conveying coal **The President.**

The President. from the faces. This was the principal cause of the great damage to the steel and iron trams in the Welsh coalfield, and the reason for their being so substantially built. Again, timber of all sizes, used at the faces and in securing roofs of the roadways, was also conveyed on or in trams. The greatest difficulty experienced in devising a tram to comply with section 62 of the Coal Mines Act, 1911, appeared to be in the arrangement of an end door. A door was indispensable in the South Wales colliery tram in order that it might discharge the rubbish at the underground faces and in the stowing of abandoned stalls and heading roadways. The door arranged for the new type of tram described by the author appeared to be a step in the right direction, inasmuch as it fitted to an angle iron end binder which practically sealed the end and thus prevented the escape of coal dust from the body of the tram. He should be glad to know if the type of door described by the author of the paper was less liable to be damaged than was the ordinary swing or lifting doors. The author was correct in stating that a true dust-proof tram was that constructed in box fashion, with two closed ends, but, as he (the President) had already indicated, that type was not practicable in Welsh steam coal collieries unless its weight-carrying capacity was decreased by reducing the height above rail level. He asked Mr. Woolley to state whether the bottom plate of the tram was riveted to the frame in such a way that the longitudinal crevice on either side of the usual type of tram was obviated, and whether he was of opinion that less dust was deposited on the floor of the roadways by the tram described in the paper.

Mr. W. O'Connor. Mr. W. O'Connor said this was a subject which would bear a great deal of discussion. It was not much to their credit as engineers that almost every colliery had a different-sized tram, often differing only slightly. They were frequently

told by makers that if colliery engineers would come together and settle upon a type of tram, it would lead to very great economy. During the war the Coal Controller threw out a similar suggestion in order to accelerate the manufacture of colliery trams. A uniform type of tram would be doubtless the achievement of an ideal state of things, but, personally, he did not think it was practicable under their varying conditions. Nevertheless, a step might be taken in that direction. There were at certain collieries a similarity of conditions and requirements, and here probably a standardised tram might be devised. Of course, trams were a comparatively modern thing in colliery work. Down to about fifty years ago it was the custom to bring out the coal in baskets ; and it was interesting to note that the wicker basket still survived in steep measures for the conveyance of coal along the stall roads from the faces to the headings. There were many points of view to be considered when they were dealing with colliery trams. First of all, there were the requirements of the section of the Act to which the President had called attention. Then they had to consider the money cost. Trams for modern colliery work locked up a large amount of capital. Then, the makers were entitled to have their say as to what a tram should be, and sometimes made suggestions which effected substantial reductions in cost. Again, the colliery mechanics had certain ideas with regard to a matter that involved a great deal of work in the workshops. Then, the collier had something to say about the trams and their facilities for filling, &c. Also, there was the point of view of traffic arrangements which might not suit the ideas of the other parties he had mentioned. And last of all, there was the manager, who had to take a wider view in order to combine the ideas of the lot so as to get the best possible result. It was curious to notice the different conclusions arrived at. For instance, in the Pennsylvania coal- Mr. W. O'Connor.

Mr. W. O'Connor.

field the customary tram was built to contain about 2 tons 10 cwt. of marketable coal, and the weight was about 3 tons 5 cwt. In their own coal-field the majority of their trams had a load of about 25 cwt.; in the Midlands they were about 12 cwt., and at some of the northern pits tubs were used as low as 6 cwt. capacity. It did seem highly desirable to bring all these views into closer harmony although impossible to adopt one standard. It might be practicable to settle on a few types, which could be made in large numbers, and various details thought out so that first cost, readiness of supply, and economy of repairs should receive adequate attention. He was going to suggest that in South Wales they might do very well with only about six types of trams running upon six different gauges of lines. Developments in tram-designs had run upon well-marked lines. He was in possession of parts of a tram that was in use in that district about 120 years ago. The axles very much resembled those used in carts nowadays. They were fastened directly to the tub of the tram, and the wheels ran loose upon them. The ancestor of that tram was no doubt designed on the horse cart of the country roads. Half a century later the colliery tram was a wooden contrivance with a box on fixed wheels. With their deeper collieries and larger outputs the tendency was to approximate somewhat to that which had been commonly in use in Glamorgan for generations. The body of the tram was of steel, and the frame and bearings made for the purpose of carrying the wheels and axles, and the wheels were loose. The specification of the tram described in the paper was, he noted, 15 inches diameter. The usual diameter in South Wales was 1 foot 5 inches diameter. Another point was, the distance between the wheels was 22 inches; in most cases, where the 1 foot 5 inches diameter was adopted, the distance between the wheels was 1 foot 9 inches—an inch less. He should like to hear Mr. Woolley's

opinion on those points. He quite agreed with the President that the angle binder at the end was a great improvement. One of the objections to the door being put inside the angle binder was that it was difficult to get a tip—they could not get the material out of the tram unless they moved the door. The loop at the top which Mr. Woolley illustrated in Fig. 2, which enabled the door to slide upon the horizontal bar carrying the top, was an arrangement originally introduced, he believed, by a lady. In the old days of ironstone working girls were employed in unloading by hand the trams, and it was one of those girls who, he thought, invented this arrangement with the idea that there should be no bother with the pin fastenings, and the door easily raised and pushed over, and the tram contents easily got at. But in this tram the idea was spoiled by the studs put in half-way, preventing the door being pushed over more than about half-way. One essential point for the expeditious working of the door was that at least one-half of it should be on the far side of the bar from the unloading, but here this stud prevented anything more than half being put over. In many places it was impossible to get the necessary height, and this loop got over that difficulty very well. In steep measures where the trams were pushed by hand this loop answered a very good purpose. He was quite in favour of the splay angle at the top of the tram. This was a very useful thing, and prevented the breakage of the lumps of coal put near the edge of the top. With regard to buffers, this was a debatable point, and he was not sure a satisfactory conclusion had yet been arrived at. He (Mr. O'Connor) was responsible for the design of buffers referred to by Mr. J. Fox Tallis in his paper in 1900, and the present one followed much on the same lines. But he had come to the conclusion that their ideas were all wrong. If anyone was engaged in replacing a derailed tram on to the Mr. W. O'Connor.

Mr. W. O'Connor.

line he did not want to have the buffers in the way all the time. A possible solution of this difficulty was a design of central buffers with a somewhat curved end which would allow the tram to go round sharp bends without unlocking. A suitable coupling adapted to central buffers would, he thought, be one solution of the problem.

Mr. J. W. Davison.

Mr. J. W. Davison said the central buffer was adopted about twenty-seven years ago. Doctor Galloway brought out a tram which was an improvement upon the old type of trams, and it had a central buffer with springs on. It also had springs over the axles. When, however, this tram was put into use in steam coal seams, the buffers often got broken. With regard to the type of tram now under notice, there was no contrivance for preventing rackings. It had been thought to introduce stays to effect this. At the collieries with which he was connected they had tried to standardise trams as much as possible, but it was difficult to standardise trams to suit different seams and different collieries. Mr. Woolley was to be congratulated upon the paper he had submitted to the Institute. It furnished them with ideas to work out.

The President.

The President said he thought the paper would be well worth further consideration, and he adjourned the discussion to the next meeting.

# RECENT DEVELOPMENTS IN GAS-FIRING STEAM BOILERS, AND IN THE UTILISATION OF WASTE HEAT, ON THE 'BONECOURT' SYSTEM.

By Major W. Gregson (late R.E.), B.Sc., A.M.Inst.C.E., A.M.I.Mech.E.

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As far as the writer of this article is aware, South Wales has as yet had no experience in the application of 'Bonecourt' principles to steam generation—either from gaseous fuel or from waste heat. Hence a short description of the later types of boilers working on this system, and of the results which have been obtained, may not be out of place at the present time, when the urgent necessity for the economical exploitation of our national fuel reserves, and for the harnessing of all available waste heat for further industrial use, are matters of national importance.

The 'Bonecourt' boiler—which derives its name from Professor Bone (now of the Royal College of Science) and the late Lieut. C. D. McCourt, who carried out their experiments on surface combustion when the former was associated with Leeds University—consists essentially of an outer shell, forming the boiler, fitted with longitudinal fire-tubes. The tubes are fitted with special packing, the mixture of gas and air being drawn through the boiler either by natural draught or by a suitably arranged suction fan, according to the size of the boiler.

Experiments carried out on a 3-inch diameter tube, 3 feet long, showed that it is possible to burn completely a mixture

of 100 cubic feet of coal gas, plus 550 cubic feet of air per hour, and to evaporate 20 to 22 lbs. of water per square foot of heating surface, the products leaving the tube at about 200° C.—meaning the transmission of 88 to 90 per cent. of the nett heat of combustion to the water. By the addition of a feed-water heater the products were further reduced to about 150° C., the thermal efficiency of the plant being thus increased to approximately 92 per cent., and exhaustive trials carried out in the first experimental boiler to be constructed to embody the above principles showed that this type of steam generator possessed three dominant features :—

(*a*) A hitherto unobtainable thermal efficiency of approximately 90 per cent. without a feed-water heater,

(*b*) A very high factor of evaporation, and

(*c*) Perfect combustion was obtainable, with very little excess air over and above the theoretical quantity required.

The results obtained from the experimental laboratory boiler were such as to justify the immediate development of the ideas incorporated in the design of this boiler for the production of a boiler which was to be a commercial proposition.

## Gas-fired Boilers.

The first commercial boiler was installed at the Skinningrove Iron Co.'s works in 1911, and was arranged to work on coke-oven gas. Exhaustive and independent tests gave thermal efficiencies, with a feed-water heater, up to 92 5 per cent. (the boiler was unlagged at the time of the tests), with an evaporation of 14 lbs. per square foot of heating surface per hour—this evaporation factor being coupled with a dryness factor of 99 3 per cent., the working pressure being 100 lbs. per square inch. This boiler was subsequently duplicated, and this installation represents the first 'Bonecourt' boiler plant to be erected as a practical proposition.

Since the date when the first Skinningrove boiler was started up nearly nine years have elapsed, and during that time the entire system has been revolutionised by Mr. P. St. G. Kirke, in order to simplify it, cheapen the manufacture, and render the boiler a more satisfactory mechanical unit, and at the same time retain the extraordinarily fine quantitative results reached by the early boilers.

The two outstanding features of a 'Bonecourt' boiler are the burners and the packing. In the early boilers the burner arrangements are somewhat complicated, each tube having an independently controlled jet; air is admitted into the burner, and an explosive mixture is shot forward into the tube at a velocity greater than the speed of ignition of the mixture, therefore preventing back-firing when running, and at the same time preventing the mixture from igniting until it impinges on the refractory material in the tube, the front part of which becomes red-hot and acts as the catalysing surface for the combustible mixture, and so accelerates and completes the combustion flamelessly in the front section of the boiler tubes. The surface of the refractory material is the zone of combustion, a large percentage of the potential energy of the gaseous mixture is converted into radiant heat, and the water receives heat both by conduction and by radiation.

As now designed, the burner is reduced to a very simple device, being a flat box having the face nearest the tube-plate perforated with holes, drilled exactly opposite the centre of each tube. The inlet to the box is controlled by a single valve, this one valve doing the whole of the gas adjustment. Furthermore, no explosive mixture, or even primary air, is admitted to the modern burner before combustion commences; the gas gets its air of combustion after leaving the burner, hence back-firing is absolutely impossible *at all speeds* of the gas. In other words, the burner may be run at anything from

full open to a point at which a mere speck of light appears at each of the gas outlets on the face of the burner.

In the modern burner the first part of the combustion takes place by flame, and mixing with air goes on in the tubes during combustion, the gases in contact with the packing being burnt at a highly accelerated rate.

The importance of the fact that back-firing is prevented under all conditions will be fully appreciated by all who have at sundry times had trouble with gas burners fitted with primary air inlets.

As stated above, the gas supply is controlled by the valve on the burner; the amount of air is controlled by the suction fan, which is invariably driven by a motor with a speed-regulating panel on the switchboard, the fan also being fitted with an adjustable damper. In the case of natural draught boilers the damper forms the controlling device. Perfect combustion is obtained by always varying the suction to suit the particular gas pressure at any load; the gas and air particles cannot escape each other, as they are forced to mix intimately in the fire-tubes. Experience has shown that in practice complete combustion results with 5 to 10 per cent. excess over the theoretical amount of air required.

It will be noted on studying the general design of these boilers that the absence of a fire-box, combustion chambers, and flues renders it impossible for gas to pass through the boiler without not only meeting, but getting intimately mixed, with air. This explains why no large excess of air is required for complete combustion, as is the case in all boilers other than the 'Bonecourt' type. This absence of quantities of excess air—which when present increase the volume of products to be exhausted from the boiler, cool the boiler, and also carry away sensible heat—is one of the factors which makes up the high thermal efficiency of the boiler.

It will be seen that any coal-fired boiler *adapted* for gas-firing has large combustion, etc., chambers inherent to its design, and in this connection, apart from the considerations of efficiency mentioned in the preceding paragraph, another important fact arises ; this is, that an explosion taking place in one of these spacious chambers might have disastrous results. In the type of boiler treated of in this article, the biggest 'chamber' is the volume of one tube minus the volume of the packing—an extremely small quantity, rendering danger from internal explosions practically non-existent.

To consider the detail of the tube packing for a few moments : the older boilers had their tubes packed with refractory material—i.e. fire-clay, etc. The use of granulated fire-clay was followed by the use of spirally-arranged refractory blocks—these being easier of insertion, mechanically stronger, and not liable to choke with dirt. Furthermore, much freer radiation from the packing to the heating surface was thus obtainable, thereby reducing the temperature on the surface of the packing. Meanwhile, the tendency of design was to decrease the diameter of the tubes, and to increase the number and length of same, and thereby secure a greater heating surface for a given size of drum. This was rendered commercially practicable by the simplified burner arrangements—for obvious reasons. However, the smaller sized tubes meant that refractory clay packing presented greater difficulties, so packing consisting of iron, resembling a twist drill, was experimented with. Cast-iron sections were used, and quite recently wrought iron has been adopted for this work, and, contrary to certain pessimistic prophecies, the iron spiral has proved an unqualified success. It is simple, easy to manufacture, mechanically strong, and apparently has an unlimited life. The resistance to oxidation is due to the fact that temperatures, even in the first section of the boiler tubes, are not high, owing to the rapid transfer of heat

to the water, and also owing to the absence of any large excess of air.

The functions of the tube packing may be summarised as follows :—

1. It accelerates the mixing of fuel and air, and consequently accelerates combustion of the mixture.

2. It transmits a proportion of the heat of combustion to the water by *radiation,* instead of by conduction alone, thereby greatly accelerating the transmission of heat.

3. It prevents the hot products from passing down the centres of the tubes without coming in contact with the heating surface, also preventing the formation of a cold inert gas or air film on the walls of the tubes.

4. It increases the length of the path of flow of the gases, and increases the heat-absorbing surface over which the gases sweep.

Furthermore, by simply varying the length of packing in each tube, the temperature of the gases leaving the boiler for the superheater, or again leaving the feed-water heater, can be readily readjusted at any time after the installation is erected and calibrated.

The nett results of the effects tabulated above is that the average evaporation per unit of heating surface can be increased to 400 per cent. above ordinary practice, without the efficiency of the boiler being in any way impaired.

The tubes being fed with water over their entire length, there is no fear of priming or of the burning-out of tubes.

Owing to the rapid heat-transference which takes place in and through the tubes—both by radiation and by conduction—the average temperature over the packing in modern 'Bonecourt' boilers varies from 650° C. to 500° C., while the maximum temperature attained for a short distance along the inlet end of the tubes rarely exceeds 850° C. Iron packing, as mentioned previously, is quite satisfactory at these temperatures.

In the older types of boiler using explosive mixtures, and where short tubes were adopted, the peak temperature was as high as 1450° C.; in these cases, refractory fire-clay packing was, and still is, used.

The suction fan pulls the gases through the tubes and over the packing at a sufficiently high velocity to ensure dust being carried right through. The power taken by the motor-driven fan is small, varying from 1 per cent. to 3 per cent. of the output of the boiler, according to conditions; this item can generally be set off against corresponding items for mechanical stoking, steam jets, or manual stoking, in other types of boilers.

Before leaving the discussion on gas-fired boilers, it should be mentioned that 'Bonecourt' boilers, up to an evaporation of 1500 lbs. of steam per hour, are now constructed to work on natural draught; the thermal efficiency is slightly lower than in the case of the larger units worked on mechanical draught, but, of course, the necessity for a fan and motor is done away with.

A number of these small boilers are at work on town gas, and are proving immensely popular. An efficiency of 86 per cent.—without a feed-water heater—is obtainable on these small natural draught units. The addition of a fan plus a feed-water heater brings this figure up to approximately 93 per cent.

Coming to questions of general design: the outside shell is not subjected to direct heating, neither is it perforated to receive tubes, as is the case of the drums of many types of water-tube boilers. Hence the main shell or drum is simple and mechanically sound. The older 'Bonecourt' boiler suffered from the defect of all drum-type boilers—i.e. that for medium and high working pressures the drum became very heavy, owing to the necessary thickness of the shell-plates. Since the days of the first 'Bonecourt' boilers a complete and radical change has been made in this question

of general design. The old boilers were of large diameter and of short length; the diameter was gradually decreased and the length increased, and the standardised designs now rarely exceed 6 feet in diameter for a single boiler, the practice being to multiply the number of drums per boiler, using either two side by side, or superimposed one on the other, and inter-connected; or else to use four—two below and two above, all inter-connected. The standard tube-length for all the larger boilers is 18 feet. When this length was first adopted—exhaustive experiments had already proved that it was the correct length—many experts were sceptical over what was considered the abnormal length of these tubes. When it is remembered that 25 feet is a common length for locomotive boiler tubes in America, and also that the tubes are always buoyed up by the water surrounding them, the earlier prejudices were quickly removed, and the actual results obtained have more than justified the standardised adoption of this tube length. The fact that the 'Bonecourt' people have never had to renew a single tube in any gas-fired boiler installed by them is a sufficient proof of the soundness of their tube designs.

The end-plates are stayed with gussets, and further staying is obtained either by making a certain number of the tubes stay-tubes or, preferably, by bell-mouthing all the tubes.

Brick flues and chimneys are entirely eliminated, the only chimney necessary being a sheet metal uptake from the fan, sufficient to clear the boiler-house roof.

The standard type of gas-fired boiler, which has been briefly reviewed above, is suitable for working on any gaseous fuel—coke-oven gas, producer gas, water gas, and, of course, town gas being typical fuels. The standardised unit of boiler, super-heater, feed-water heater, and suction fan, all in line, makes a particularly simple, neat, and workmanlike steam generator.

Fig. 1 shows the general construction of one of the older boilers. This boiler—installed at a works in the Midlands, and running on raw producer gas, is 10 feet diameter by 15 feet long, and evaporates 19,600 lbs. of steam per hour from and at 212° F. The working pressure is 120 lbs. per square inch.

Fig. 2 shows a twin-drum boiler working on coke oven gas.

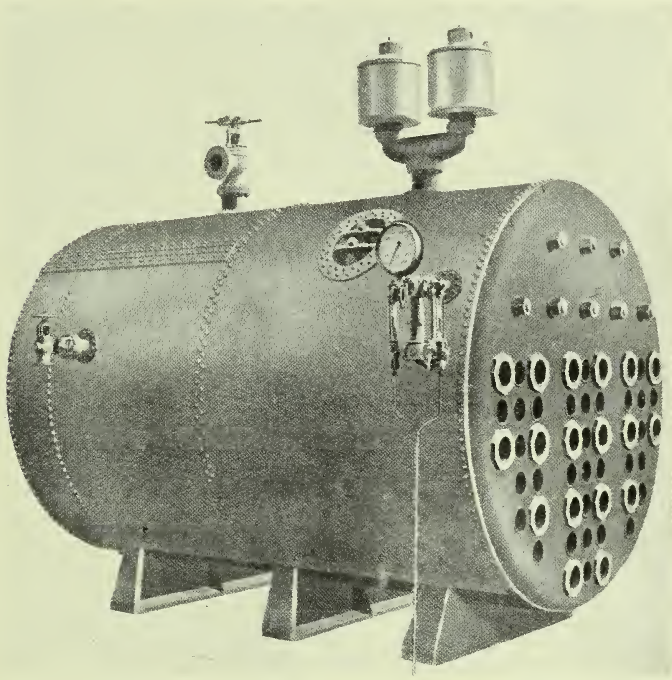


FIG. 1.

The drums are 4 feet 6 inches diameter, with a tube length of 15 feet $4\frac{1}{2}$ inches. The unit gives 12,000 lbs. of steam per hour (from and at 212° F.), with a 10-inch suction, and is suitable for a working pressure of 150 lbs. per square inch. Fig. 3 is another view of this boiler, showing the burners.

Neither of the above boilers works on an explosive mixture, but it will be noticed that the burners on the boiler in Fig. 2 and Fig. 3 are independently controlled for each jet; the later

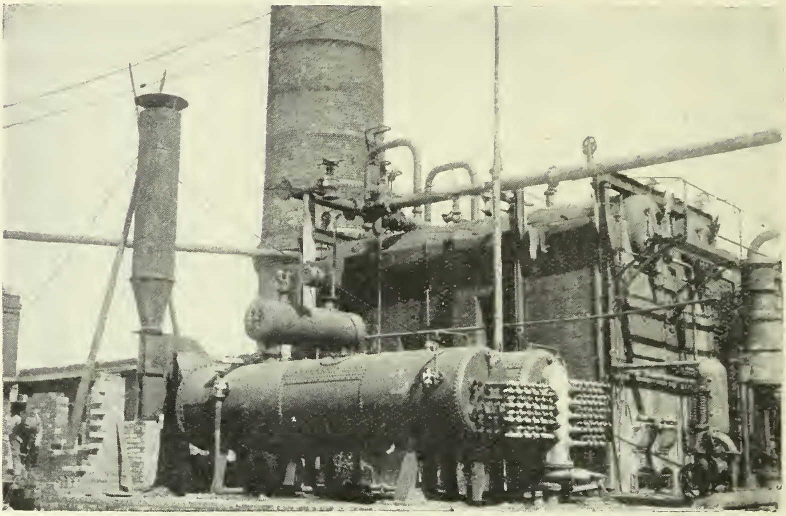


Fig. 2.

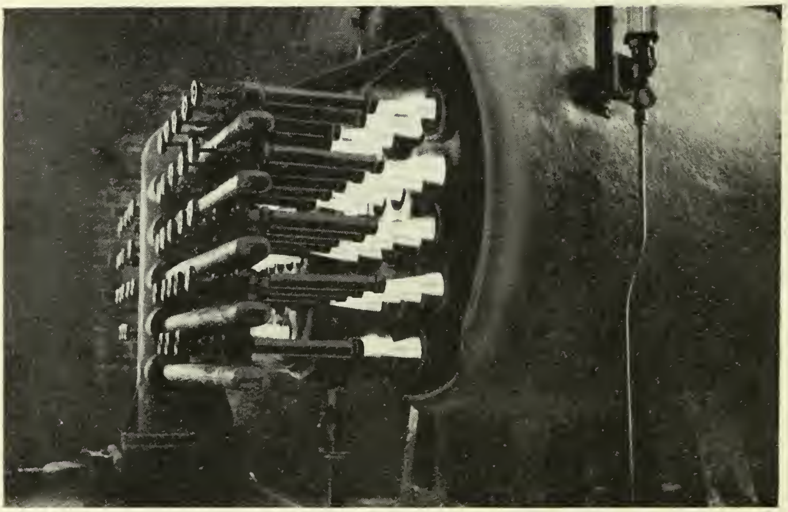


Fig. 3.

types of burner, as explained above, have single control for each box.

The boiler in Fig. 4 is 2 feet 6 inches diameter by 10 feet long and gives 1500 lbs. of steam per hour from and at 212° F., working on a 2-inch suction (with rich gas). The new type

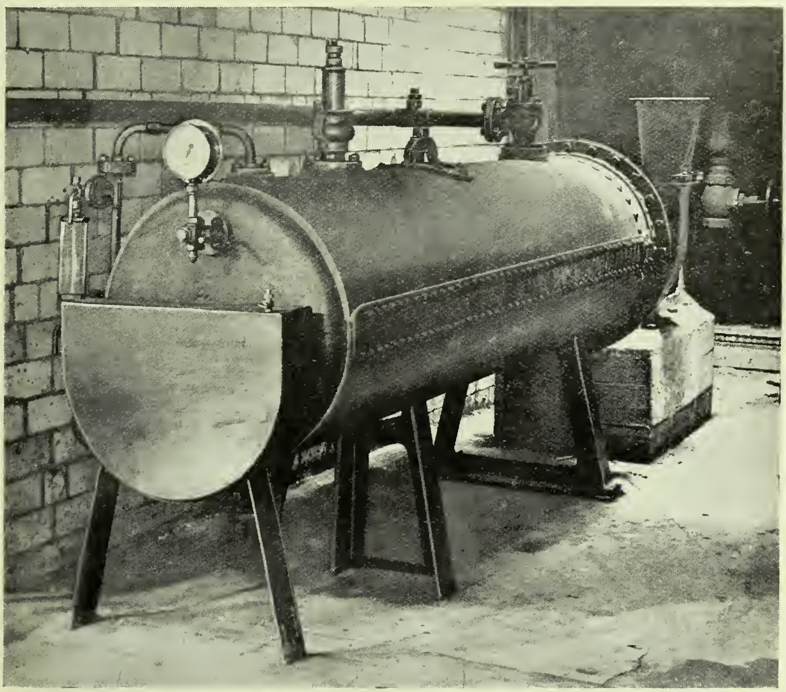


Fig. 4.

of burner-box can readily be seen: the front (i.e., facing the boiler) has drilled holes to form the gas jets.

The gas is controlled by one inlet valve (valve and gas main not shown on photograph).

Summarised briefly, the high thermal efficiency of the 'Bonecourt' boiler in its present form can be attributed to two factors:—

(*a*) Perfect combustion with very little excess air.

(*b*) Rapid heat transference to the water—by radiation as well as by conduction.

The chief improvements which have been effected in general design during the past few years are—

(*a*) Reduction in diameter of drums.

(*b*) Adoption of the multi-drum principle for larger units and high pressures.

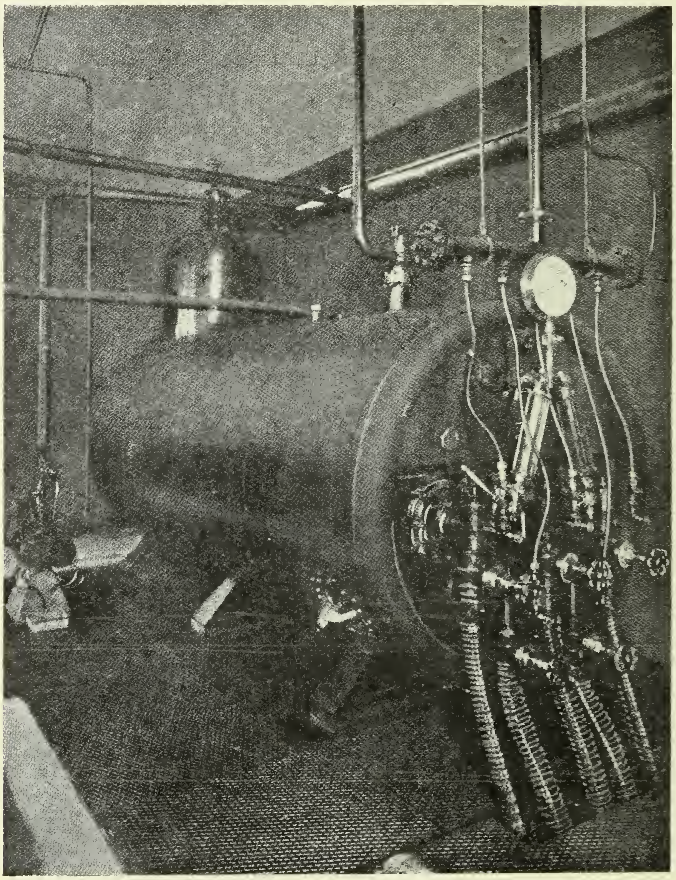


Fig. 5.

(*c*) Reduction in tube diameter (consequent on use of simplified burner, rendering larger number of tubes practicable) and greater tube length, thereby giving a much greater heating surface per drum of fixed diameter.

(*d*) Abandonment of the explosive mixture.

(*e*) The addition of superheaters to the units.

(*f*) Twisted metallic tube packing instead of refractory material.

### Oil-fired Boilers.

Two types of boiler have been evolved for use with oil fuel: a boiler similar in type to the gas-fired boiler, but with larger tubes and with oil-burners substituted for gas burners; and, secondly, a boiler which also comprises a combustion chamber packed with refractory material, a single burner—of any good type—being used.

Fig. 5 represents a boiler of the first type. This particular boiler is 5 feet diameter by 14 feet long, is designed for a working pressure of 110 lbs. per square inch, and is fitted with a feed-water heater. A test on this particular boiler is given as Appendix II herewith.

A modern representative of the second class is shown on Plate 5; the particular boiler there shown is being installed in Yorkshire, and is designed to give 4800 lbs. of steam from and at 212° F. per hour. It is 4 feet 6 inches diameter by 10 feet long between tube plates, the length of shell being 16 feet 9 inches.

Boilers of the second type have a greater evaporative capacity than similar sized boilers of the first category; this is because the latter boilers have a large number of small tubes, hence they possess a relatively larger heating surface than boilers of the former class, which have a moderate number of larger diameter tubes, each fitted with a separate oil-jet burner.

It is hoped to adapt this second type of boiler for firing with pulverised fuel, but at present this is only in the early experimental stage. Incidentally, it might be remarked that the ordinary return-tube marine boiler can be converted to burn oil or pulverised fuel on the 'Bonecourt' system.

## Utilisation of Waste Heat.

It seems to be a common fallacy to suppose that any ordinary boiler will work efficiently as a waste-heat boiler ; as a matter of fact, the relations between surface exposed to gases, length and diameter of tubes, and draught need careful investigation for each individual case if really efficient results are desired. Owing to the fact that air cannot leak into the waste gases and so cool them, the fire-tube boiler is the best type of boiler for this class of work, especially when working on induced draught ; and this subject opens up a very wide field for the 'Bonecourt' type of boiler. The general arrangement of the boiler, etc., is similar to that for gas-firing, with the exception that no burners are required, and that the superheater is generally arranged on the inlet side of the boiler, and not between the boiler and feed-water heater.

In many instances, the low temperature of the products of combustion available for steam raising renders the installation of ordinary boilers prohibitive, owing to the high capital cost of the relatively big boiler plant necessary to deal with the hot gases, and at the same time the amount of steam generated would be comparatively small. The adoption of 'Bonecourt' principles for waste-heat utilisation means a smaller boiler for dealing with the gases, coupled with higher thermal efficiency. The tube packing when used increases the heat transmission through the walls of the tube by radiating heat, and also causes the hot gases to impinge repeatedly on the tube walls.

When dealing with waste gases the latter often contain a large proportion of dust in suspension. By using a moderately high suction—which incidentally also reduces the size and, therefore, the first cost of the installation—dirt can generally be successfully carried through the tubes ; but in extreme cases the system adopted is to omit the tube packing and utilise much

smaller tubes than the standard (to increase the heating surface), and by suitably proportioning length to bore to suit the draught and temperature of the products, the efficiency of the boiler is maintained.

If a feed-water regulator be fitted, the waste-heat boiler is unique in requiring no attendance, as well as no fuel. In other words, if a waste-heat boiler unit be installed, the cost of operation is *nil*, maintenance charges are negligible, and a continuous supply of steam is available for no further monetary outlay.

Roughly speaking, the waste-heat field may be subdivided into two divisions :—

(*a*) Gas-engine exhausts.

(*b*) Discharges from industrial apparatus (furnaces, soaking-pits, retorts, etc.).

The discharge temperature of a gas-engine averages from 450° C. to 500° C., and this exhaust contains some 40 per cent. of the total heat energy supplied to the engine as gas. 'Bonecourt' boilers, specially designed for dealing with gas-engine exhaust products, are giving excellent results.

To get an idea as to the economies effected by this class of boiler : a 500 B.H.P. gas-engine running twenty-four hours a day, six days a week, at 80 per cent. full load, has its exhaust dealt with by a waste-heat boiler. This boiler gives 1100 lbs. of steam per hour from and at 212° F. at 80 per cent. full load, which is equivalent to the results obtainable by burning some 300 tons of coal per annum.

Experience has shown that, with gas-engines of 100 B.H.P. or less, the best results are obtained by using water heaters, and not steam boilers. This hot water is available for boiler feeding, or for industrial or heating purposes.

In the case of steam boilers of the 'Bonecourt' type working on gas-engine exhausts, steam is available at working pressure in about 30 minutes from starting up the gas-engine, showing

the remarkable rapidity of heat transference in this class of steam generator.

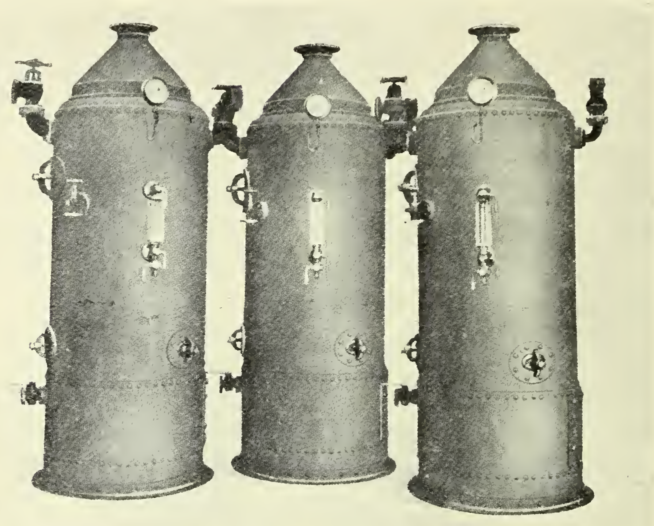


Fig. 6.

The boilers shown in Fig. 6 are 10 feet 6 inches overall height by 3 feet 6 inches diameter, and are designed to work

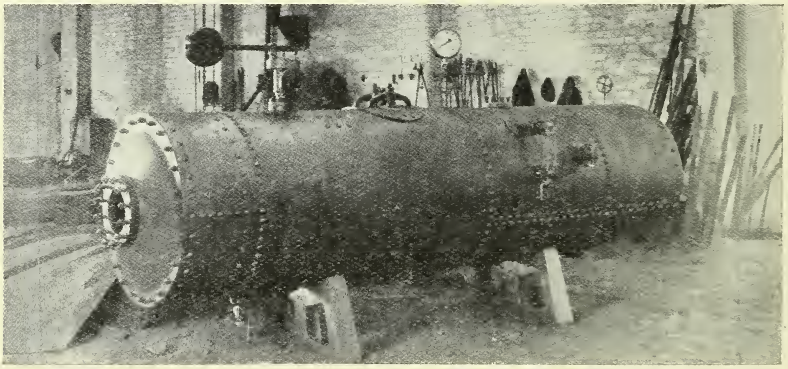


Fig. 7.

on 500 B.H.P. gas engines. Fig. 7 shows a boiler 3 feet 6 inches diameter by 13 feet long, built for a 750 B.H.P.

'Westinghouse' gas-engine. In each case the tube length is 9 feet.

The hot gases discharged from industrial apparatus—especially from non-regenerative furnaces—often contain over 70 per cent. of the heat available from the fuel. In many cases the employment of waste-heat boilers has been vetoed owing to the small evaporation obtainable per unit of heating surface, and the consequently bulky nature of the boiler plant. However, the intensified evaporation of a 'Bonecourt' unit means a much smaller and more compact installation.

Take the case of an ordinary open-hearth furnace. The following is a typical heat balance-sheet :—

| | Per Cent. |
|---|---|
| Heat utilised in furnace . . . . | 27 |
| Radiation losses of furnace and regenerators | 29 |
| Heat lost in producer ashes . . . | 3 |
| Radiation loss from producers . . | 10 |
| Heat lost in flue gases leaving the system | 31 |
| | 100 |

Assuming the coal burnt in the producers to possess a calorific value of 13,000 B.T.U.'s per lb., every pound of coal gasified results in the passage of 4030 B.T.U.'s up the chimney. Of this, a waste-heat boiler of the 'Bonecourt' type recovers 80 per cent., thus affording 3200 B.T.U.'s for steam generation —this being equivalent to 2·8 lbs. of steam at a gauge pressure of 120 lbs. per square inch, raised from cold feed.

The figure of 80 per cent. is taken from a typical average case, and of course depends on the temperature and specific heat of the inlet gases.

Hence a 35-ton furnace, consuming 3000 lbs. of coal per hour, will give 8400 lbs. of steam per hour under these conditions. Of this, a maximum of 5 per cent. would be absorbed in driving the suction fan, thus leaving about 8000 lbs. per hour available for general power purposes.

The heat balance-sheet now becomes—

| | Per Cent. |
|---|---|
| Heat utilised in furnace . . . . | 27 |
| Heat utilised as steam . . . . | 23 |
| Radiation losses, furnace and regenerators | 29 |
| Radiation loss from producers . . | 10 |
| Heat equivalent of fan-power . . . | 2 |
| Heat lost in producer ashes . . . | 3 |
| Heat lost in flues, leaving boiler . . | 6 |
| | 100 |

In other words, the percentage of heat utilised in the furnace system is increased from 27 per cent. to 50 per cent. by the use of waste-heat boilers.

Fig. 8 shows a waste-heat boiler erected to take the outlet gases from a steel furnace. This particular unit works on natural draught, but in most installations of this type induced draught is utilised, 2 inches of w.g. being the standard for a boiler, and 3 inches if a boiler plus feed-water heater is supplied.

In a case recently investigated for a well-known glass-making firm, 8000 lbs. of steam per hour was available from each regenerative furnace.

It is rather interesting to note that practically all the waste-heat boilers put in by the 'Bonecourt' people have been either 100 per cent. per annum investments—i.e., the cost of installation has been recovered on the saving in fuel in the first year—or else even better results have been obtained.

The following table, showing a few sources of waste heat, indicates what can be done in this field by the installation of suitably designed steam generators. In each case, typical average temperatures and specific heats have been taken for the waste gases :—

SOME SOURCES OF WASTE HEAT.

| Plant | Percentage of oxygen in the products. | Nature of the fuel used. | Temperature of the products of combustion leaving the plant. | Percentage of the nett calorific value of the fuel normally lost in the products of combustion, no waste-heat boiler installed. | Thermal efficiency of 'Bonecourt' waste-heat boiler generating steam at 100 lbs. gauge pressure without economiser. | Thermal efficiency of 'Bonecourt' waste-heat boiler generating steam at 20 lbs. gauge pressure without economiser. |
|---|---|---|---|---|---|---|
| | | | | | Per cent. | Per cent. |
| Non-regenerative coke-oven . | 10 | Coke-oven gas | 1,100° C. | 81 | 80 | 83·3 |
| Non-regenerative re-heating furnace . . . . | 10·8 | Coal | 1,100° C. | 86·3 | 80 | 83·3 |
| Regenerative coke-oven . | 10 | Coke-oven gas | 600° C. | 42·2 | 65·7 | 70·4 |
| Regenerative steel re-heating furnace . . . . | 5 | Producer gas | 600° C. | 40 | 65·3 | 71·7 |
| Regenerative open-hearth furnace . . . . | 5 | Producer gas | 500° C. | 33 | 59·5 | 66·8 |
| Gas-engine. Full load . | 9 | Producer gas | 480° C. | 41 | 57 | 66·4 |
| Regenerative gas-works retort ovens . . . . | 11·7 | Producer gas | 410° C. | 42·7 | 50·7 | 61·2 |
| Regenerative glass furnace . | 2·86 | Producer gas | 410° C. | 23·9 | 50·3 | 60·4 |

## Notes on Appendices.

Appendix I gives figures of a test carried out on a 'Bonecourt' gas-fired boiler working on coke-oven gas.

Appendix II refers to a test on an oil-fired boiler (the

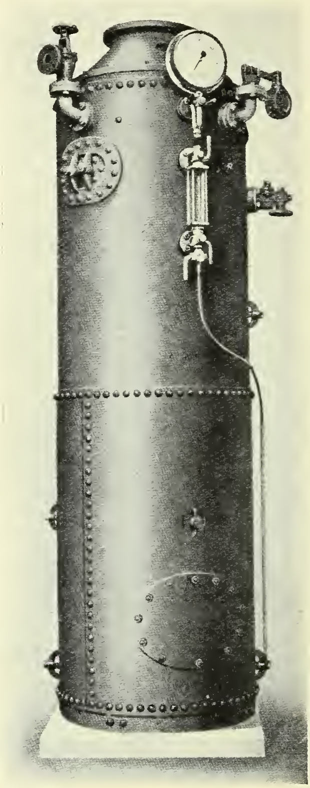


Fig. 8.

boiler illustrated in Fig. 5), while Appendix III is an evaporation test carried out by an independent firm on a small boiler working on town gas, and shows the high evaporation which can be obtained in boilers of the 'Bonecourt' type. Appendix IV gives details of a test on a waste-heat boiler working on a gas-engine at low load, and is particularly interesting as

the inlet temperature to the boiler was only 365° C. On full load, this temperature is generally in the region of 500° C. in most engines. Boilers working on old engines have given as much as 4 lbs. of steam per B.H.P. hour.

## Notes on Plates.

Plate I represents a simple 'Bonecourt' unit, without feed-water heater or superheater. The particular boiler shown works on producer gas, and evaporates up to 5000 lbs. of steam per hour from and at 212° F. Plate II is a larger boiler, evaporating up to 20,000 lbs. of steam from and at 212° F. per hour, with coke-oven gas and with a 10-inch w.g. suction, and is complete with feed-water heater and superheater. Note that the boilers and the feed-water heater have their tubes arranged in two nests to facilitate cleaning. Plates III and IV show multi-drum types of boiler; in the case of vertical combinations, it should be observed that water is fed into the upper drum, and overflows through the vertical down-pipe into the lower drum, to which is fitted the water-gauges. The steam from the lower drum passes into the steam space of the upper drum, thence to the superheater.

The units shown in these last two plates evaporate up to 40,000 lbs. of steam from and at 212° F. per hour when running on coke-oven gas, and up to 32,000 lbs. on producer or similar gas of low calorific value, the suction in each case being equal to 10 inches of water.

It is interesting to note that the vertical twin occupies a space 50 feet long by 10 feet wide, complete with feed-water heater, superheater, and fan installation. To get a similar evaporation from a Lancashire boiler installation would mean taking up at least five times this floor space, apart from the heavy brick chimney, etc., which the latter type of plant requires.

It should be mentioned that the standard tube for small 'Bonecourt' boilers is now 2 inches outside diameter, and for the larger boilers 3 inches outside diameter.

Plate V shows a typical oil-fired unit, for working on residual oil. This boiler is designed for 4800 lbs. of steam from and at 212° F. on a 4-inch suction.

## Conclusion.

No paper on the subject of gas-firing applied to steam boilers is complete without reference to the recently published report by the 'Nitrogen Products Committee.' A sub-committee was formed, which dealt purely with the question of the gas-firing of boilers, and a memorandum was prepared by this sub-committee in December 1916, and is now published as an appendix to the full report issued by the 'Nitrogen Products Committee.'

Their conclusions are summed up as follows :—

(1) The system of gas-firing in tubes is apparently so efficient that it must be considered ;

(2) No 'Bonecourt' boilers for high pressures and large outputs have yet been made ;

(3) The 'Bonecourt' Company's designs for such boilers, with or without superheaters, are not satisfactory ; and

(4) It is quite possible to design and manufacture a satisfactory gas-fired boiler with all the thermal advantages of the 'Bonecourt' type.

The report goes on to say that during the interval which has elapsed since these conclusions were framed (i.e. 1916 to 1920) considerable improvements in the design of high-pressure boilers of the 'Bonecourt' type have been made, and that designs submitted by the Company in March 1919 comprise a plurality of small diameter shells, instead of the single shell, which latter in large high-pressure boilers gives an excessive thickness of the shell and end-plates and involves transport difficulties.

The memorandum further suggests the division of the complete boiler unit into three sections, each to be built separately. The reader will see, on examining Plates II, III, and IV herewith, that the standard 'Bonecourt' design of the present day already conforms to these ideas, and has eliminated all the disadvantages referred to in the 1916 report.

The superheaters referred to in the memorandum were at that time (1916) of the locomotive type—a certain number of tubes being allocated for the superheater units. The new 'Bonecourt' superheater (see Plates II, III, and IV) is of a totally different design, and the report referred to further states :

'In respect also of the superheater and of other details, these designs differ radically from those proposed in 1916.'

The possibilities of power production from gas evolved during processes for the distillation of coal and peat are immense. Whereas for small powers the gas-engine at present holds the field, for larger power and for simplicity and reliability the Turbine-cum-Bonecourt type of boiler combination represents the ideal power-station equipment.

The writer has several times been asked to quote actual comparative costs for steam-raising in big power plants by gas and by coal fuel. Take the case of a by-product recovery coke-oven installation, where there is a surplus of gas over and above that required for power purposes in the installation itself. Suppose this surplus gas be sold to the local municipal electrical authorities (or to any other body who wish to generate electricity) at 9*d.* per thousand cubic feet, then, if the gas be burnt in 'Bonecourt' units complete with economisers, the gas fuel will be equivalent for steam-raising purposes to coal of 12,000 B.T.U.'s at 33*s.* per ton burnt in water-tube boilers (with economisers), in each case approximately 625 lbs. of steam from and at 212° F. being available per 1*s.* of fuel cost.

The entire elimination of coal and ash handling problems, the absence of brickwork for flues, chimneys, &c., the small size of a 'Bonecourt' boiler plant compared with a boiler installation of any other type, and the fact that one stoker per shift can easily look after the whole range of 'Bonecourt' boilers, coupled with the low first cost of the installation, are strong arguments in favour of boilers of the class under consideration for central power-station work. Furthermore, each unit permits of simple gas regulation to suit varying loads.

Supposing we have a power-station which requires 120,000 lbs. of steam from and at 212° F. per hour when running on maximum load, then four 'Bonecourt' units of the types and size shown in Plates III and IV would be capable of giving this output under easy steaming conditions, when working on coke-oven gas; in fact three of the units when working up to full capacity would give the total steam required, hence one unit could always be looked upon as a stand-by.

The small space occupied by these units is remarkable when compared with the boiler space which would be required for a similar steam output from any other type of steam generator.

*Note on Comparative Costs of Coal and Gas Fuel.*

(*a*) Coke oven gas of 500 B.T.U.'s. 'Bonecourt' unit efficiency = 90 per cent. Cost of gas, 9*d*. per 1,000 cubic feet.

Steam available for one shilling's worth of gas

$$= \frac{500 \times 1000 \times 12 \times 0{\cdot}9}{966 \times 9}$$

$$= 625 \text{ lbs. from and at } 212° \text{ F.}$$

(*b*) Coal of 12,000 B.T.U.'s per lb. Cost = 33*s*. per ton. Efficiency of water-tube boiler unit = 75 per cent.

Steam available for one shilling's worth of coal

$$= \frac{12000 \times 2240 \times 0{\cdot}75}{966 \times 33}$$

$$= 625 \text{ lbs. from and at } 212^\circ \text{ F.}$$

## Appendix I.

*Test made on an unlagged Bonecourt Boiler, working on Coke-Oven Gas (with Feed-water Heater).*

Duration of test . . . . . . . 10 hours.

Calorific value of gas . . . . . . 510 B.T.U.'s

(mean of 29 determinations, corrected to N.T.P.).

Total gas metered, corrected to N.T.P. = 101,968·6 cu. ft.

∴ *Total heat units available* = 52,003,986 *B.T.U.'s.*

| | | |
|---|---|---|
| Mean steam pressure (45 observations) | 97·2 | lbs. per sq. in. |
| Barometer . . . . . . | 14·3 | ,, ,, ,, |
| Mean absolute pressure . . . | 111·5 | ,, ,, ,, |

Temperature of cold feed . . . . . 62·8° F.

,, ,, feed to boiler . . . . . 129·8° F.

Dryness of steam . . . . . . 99·3 per cent.

Heat units in one lb. of wet steam evaporated at 111·5 lbs. per square inch absolute (from water at 62·8° F.):

| | |
|---|---|
| 99·3 per cent. steam . . . . . . | 1145·4 B.T.U.'s |
| 0·7 per cent. water . . . . . . | 1·9 |
| | 1147·3 |

Total water evaporated . . . . . 42,019 lbs.

∴ *Total heat units utilised* . . . . . 48,208,399 lbs.

∴ *Efficiency* = 92·7 per cent. (*unlagged*).

Total evaporation from and at 212° F. = 49,824 lbs. in. 10 hrs.

Heating surface of boiler (tubes) . . . 352 sq. feet.

∴ *Evaporation* (from and at 212° F.) *per square foot of heating surface per hour* = 14·1 lbs.

Fan motor took 13·8 amps. at 440 volts throughout test = 8·15 E.H.P.

Corresponding steam equivalent = 122·6 lbs. per hour.

*Nett efficiency of boiler and feed-water heater, after deducting power required by fan = 90·2 per cent. (unlagged).*

Average temperature of products leaving boiler = 384·7° F.

„ „ „ „ „ heater = 203° F.

Steam temperature . . . . . . 335·5° F.

Following is a typical analysis of the coke-oven gas burned during the test :

| | Per Cent. |
|---|---|
| $CO_2$ | 2·5 |
| $O_2$ | 0·5 |
| Unsaturated hydrocarbons | 3·2 |
| CO | 6·5 |
| $CH_4$ | 28·0 |
| $H_2$ | 48·0 |
| $N_2$ | 11·3 |
| | 100·0 |

## Appendix II.

*Test on Bonecourt Oil-Fired Boiler (with Feed-water Heater).*

| | |
|---|---|
| Steam pressure | 110 lbs. per sq. in. g. |
| Temperature of products leaving boiler | 608° F. |
| „ „ „ „ heater | 275° F. |
| „ „ cold feed | 43° F. |
| „ „ feed from heater | 119° F. |
| „ „ steam | 344° F. |
| Duration of test | 3 hours |
| Total water evaporated | 7,625 lbs. |
| ∴ Water evaporated per hour | 2,542 lbs. |
| Water evaporated per hour from and at 212° F. | 3,085 lbs. |
| Heating surface of boiler | 123·7 sq. ft. |

*Steam per sq. ft. of heating surface*, from and at 212° F. = 25 lbs.

Total oil burned . . 545 lbs., i.e. 181·8 lbs. per hour.

Water evaporated from and at 212° F. per lb. of oil = 17·0 lbs.

Nett calorific value of oil per lb. . . 17,800 B.T.U.'s

$$\therefore \textit{Efficiency of boiler and heater} = \frac{7625 \times 1175{\cdot}9 \times 100}{545 \times 17800} = 92{\cdot}5\%$$

## Appendix III.

*Test on a Gas-Fired Bonecourt Boiler, with Feed-water Heater (independent test by boiler experts).*

| | |
|---|---|
| Length of trial . . . . . . . | 6 hours. |
| Total gas used, reduced to N.T.P. . . . | 9,030 cu. ft. |
| Calorific value of gas, at N.T.P. . . . | 516 B.T.U.'s |
| ∴ Total heat available . . . . | 4,670,000 B.T.U.'s |
| Steam pressure . . . . | 112·4 lbs. per sq. in. |
| Temp. of feed before heater . . . . . | 49° F. |
| ,, ,, ,, after ,, . . . . . . | 119° F. |
| Quantity of water converted to steam . . | 3690 lbs. |
| Heating surface of boiler . . . . . | 21 sq. ft. |
| ∴ *Equivalent evaporation from and at* 212° F. *in lbs. per square foot of heating surface per hour* . | 35·8 lbs. per sq. ft. |
| Heat utilised . . . . . . . | 4,320,000 B.T.U.'s |
| *Efficiency* . . . . . . | 92·5 per cent. |
| Steam . . . . . . . | 'Practically dry.' |

## Appendix IV.

*Test carried out on a Waste-Heat Boiler working in conjunction with a New* 450 *B.H.P. 'National' Gas-Engine, coupled to Generator.*

| | |
|---|---|
| Duration of test . . . . . . | 23 minutes. |
| Temperature of inlet products . . . . . | 365° C. |

| | |
|---|---|
| Temperature of outlet products . . . . | 185° C. |
| Steam pressure . . . . . . | 100 lbs. per sq. inch (gauge). |
| Steam temperature . . . . . . . . | 170° C. |
| Difference between steam and outlet products to atmosphere . . . . . | 15° C. |
| Water evaporated . . . . . . | 252 lbs. i.e. 656 lbs. per hour. |
| Volts on dynamo . . . . . . . . | 400 |
| Amperes on dynamo . . . . . . | 470–500 |
| Average electrical H.P. . . . . . . . | 260 |
| ∴ B.H.P. (assuming efficiency of generator 95 per cent.) = 274 (i.e. only 61 per cent. full load). | |

$\therefore$ Water evaporated per hour per B.H.P. $= \frac{656}{274} = 2{\cdot}4$ lbs. (this was obtained on an *unlagged* boiler).

(Note particularly low temperature of the inlet products.)

## The Discussion.

Major Gregson.

Major GREGSON in supplementary remarks said—

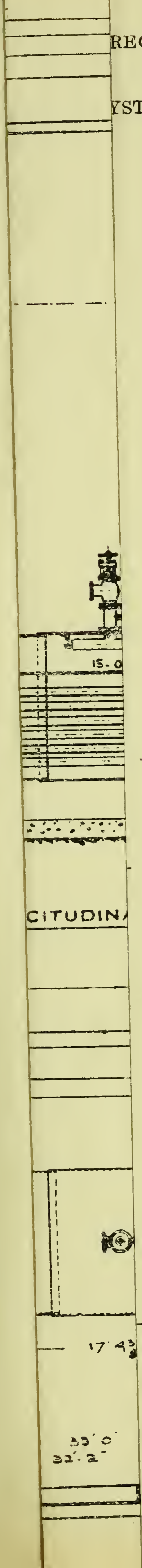
I originally intended my paper to be merely descriptive and general, my aim being to sketch the development of the adoption of 'Bonecourt' principles to steam raising, together with a general description of typical units representing the different phases of 'Bonecourt' development.

It seems, however, extremely difficult to generalise on a subject such as this, as one cannot help getting down to specific cases and going into figures—in the first case to support the contention that the Bonecourt boiler is a high efficiency steam generator, and in the second case owing to the fact that the engineer not only possesses a technical mind but also a

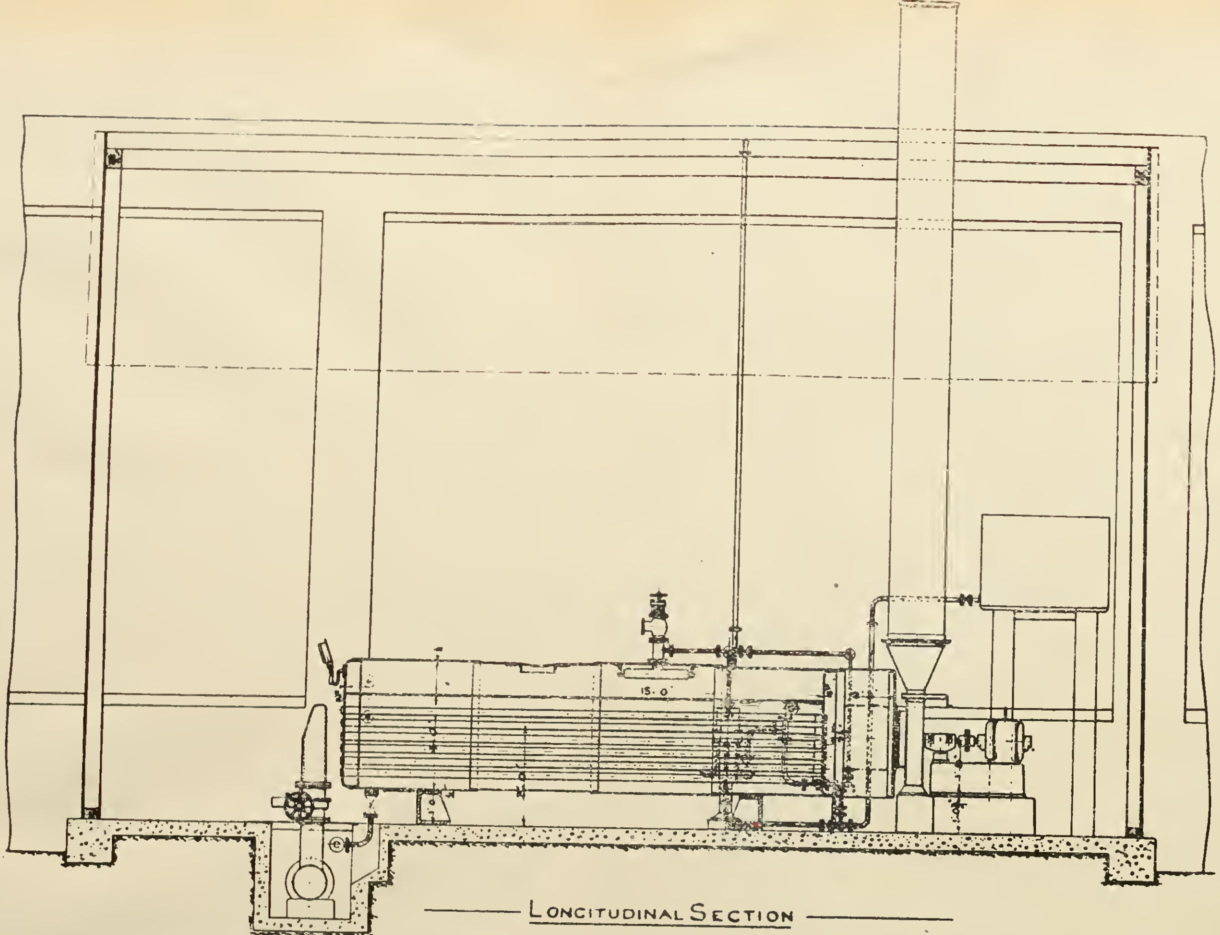
PLATE I.

REGSON'S

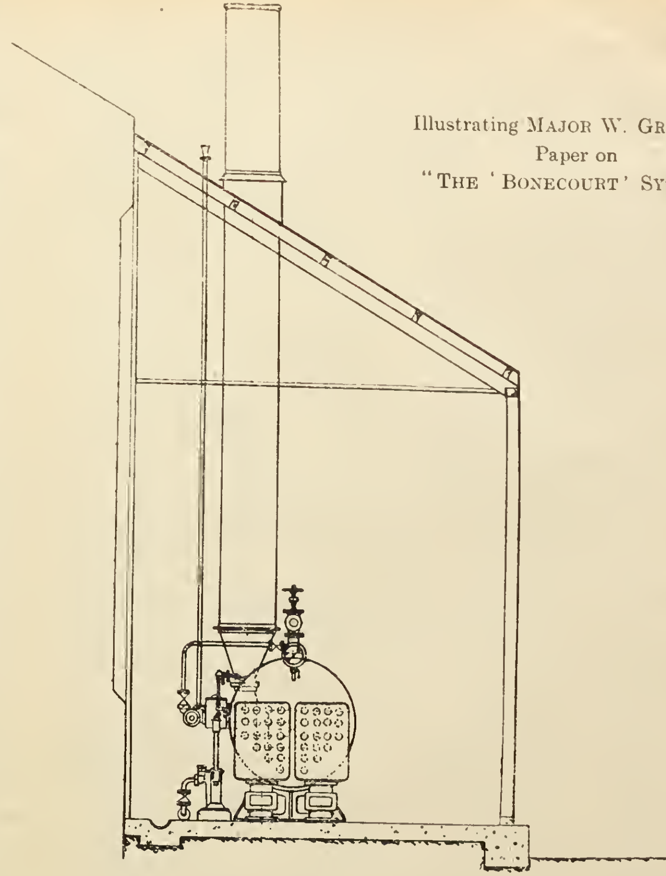
YSTEM"



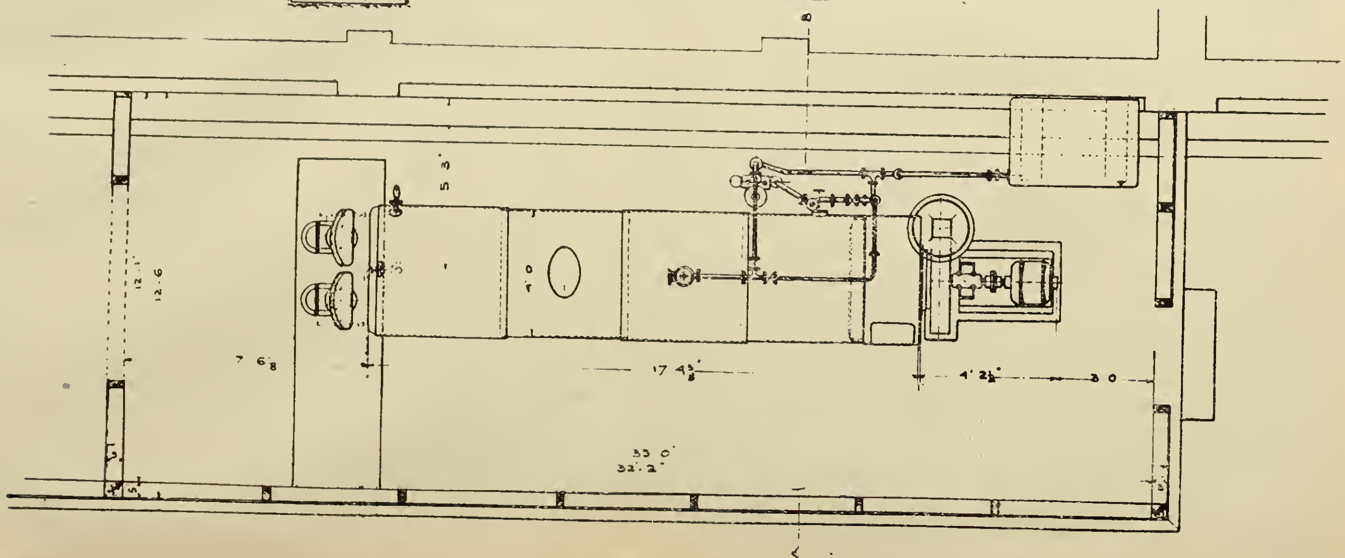
Illustrating Major W. Gregson's
Paper on
"The 'Bonecourt' System"

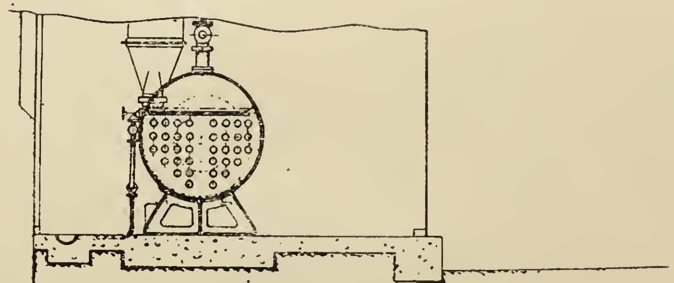


Longitudinal Section



Front View





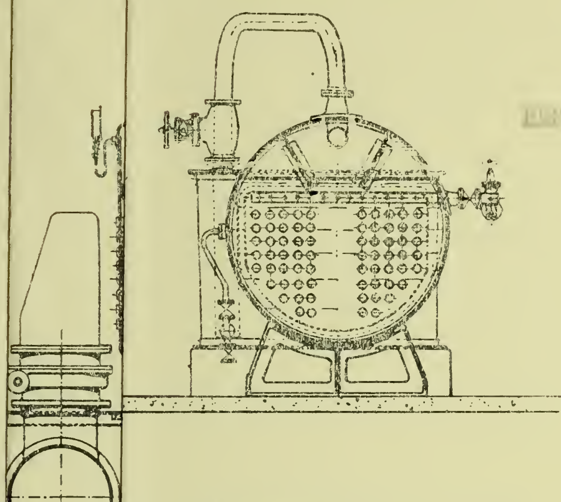
Transverse Section A B

General Arrangement
of
4′ 0″ × 15′ 0″ "Bonecourt" Gas Fired Boiler
with Induced Draught Plant, Feed Pump and Injector

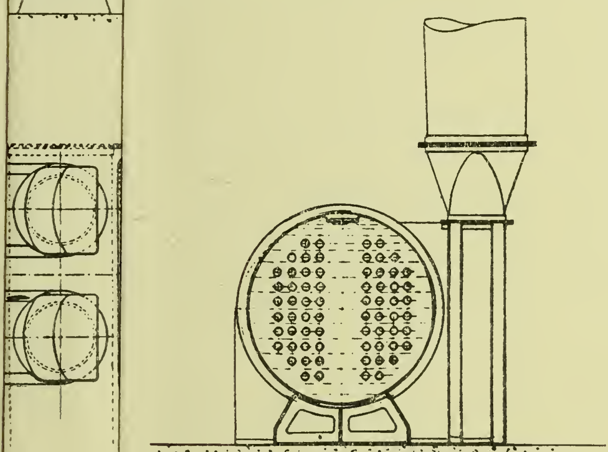
PLATE II.

ing MAJOR W. GREGSON'S Paper on
THE 'BONECOURT' SYSTEM"





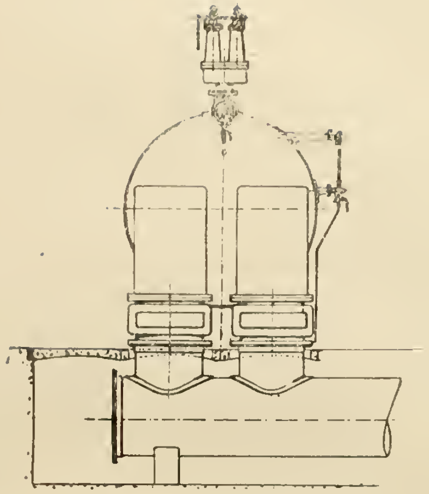
TRANSVERSE SECTION A.B



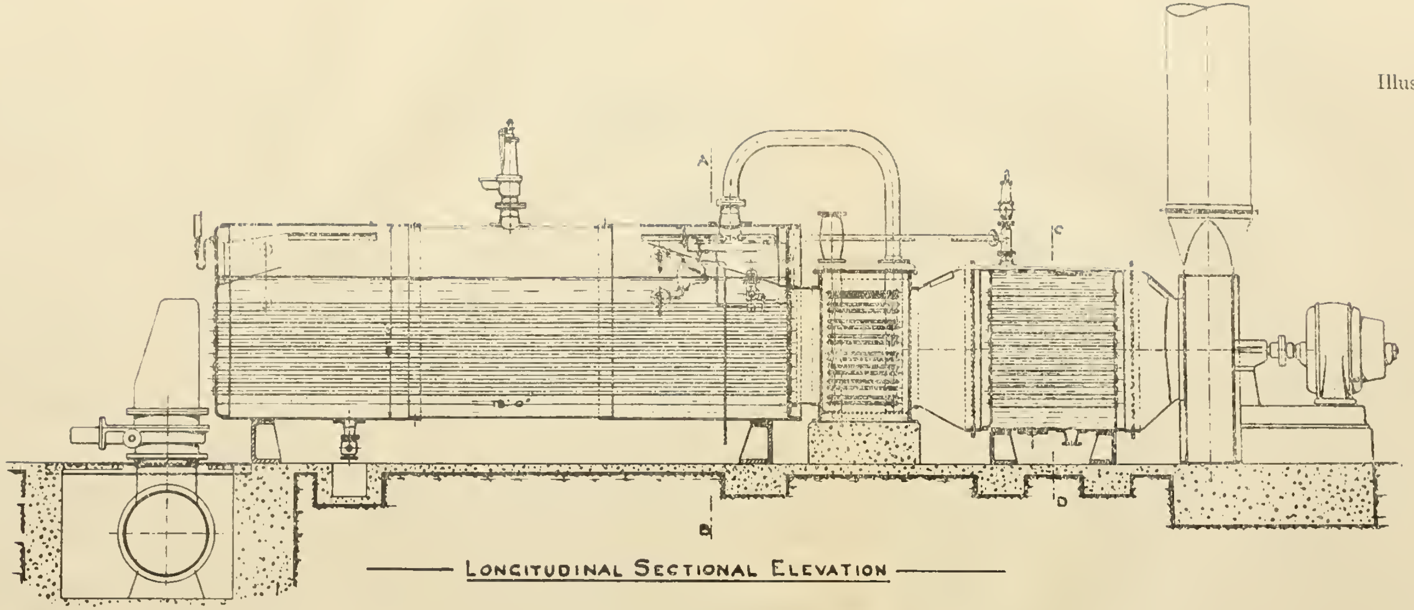
TRANSVERSE SECTION C.D

Illustrating Major W. Gregson's Paper on
"The 'Bonecourt' System"

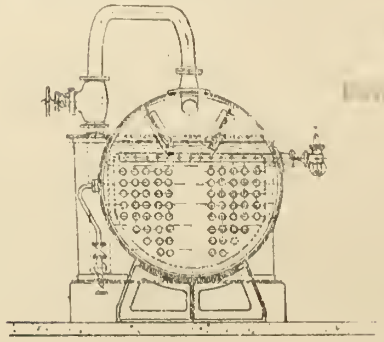




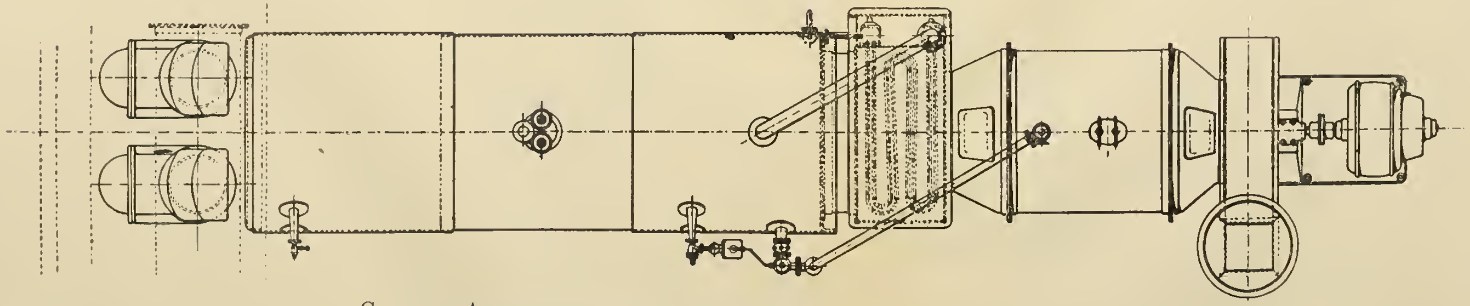
Front View

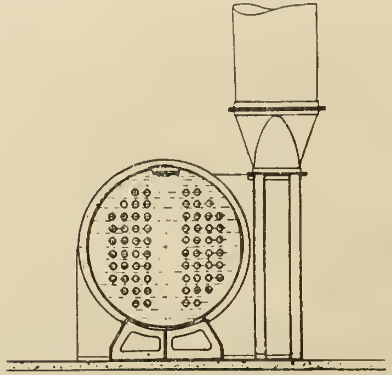



Longitudinal Sectional Elevation



Transverse Section A B



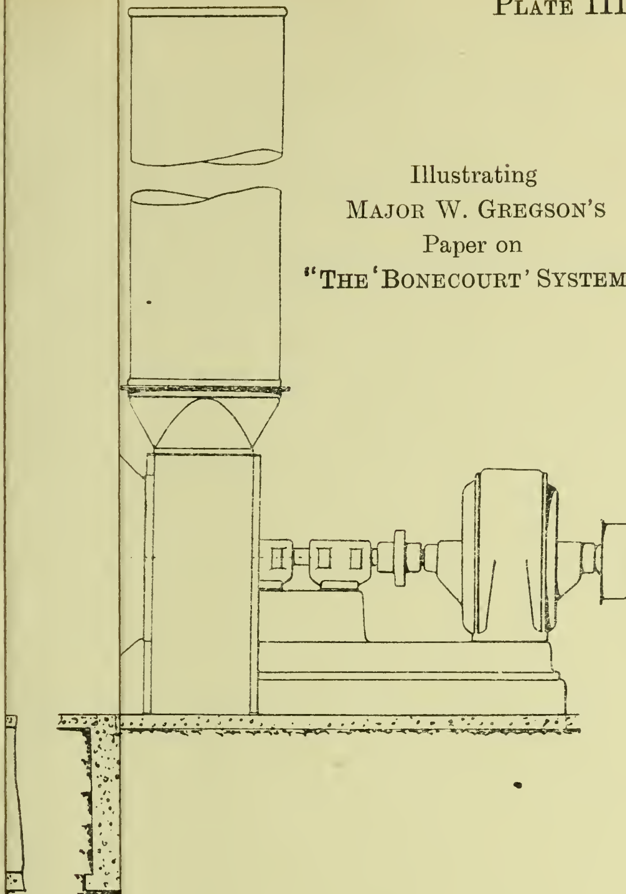


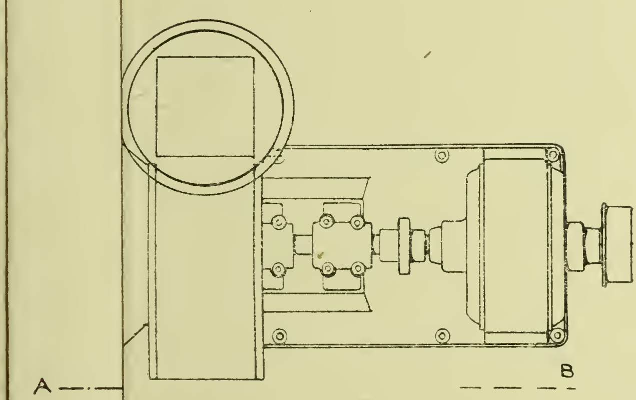
Transverse Section C D

General Arrangement of
"Bonecourt" Patent Gas Fired Boiler
with Superheater, Economiser and Induced Draught Plant

Plate III.

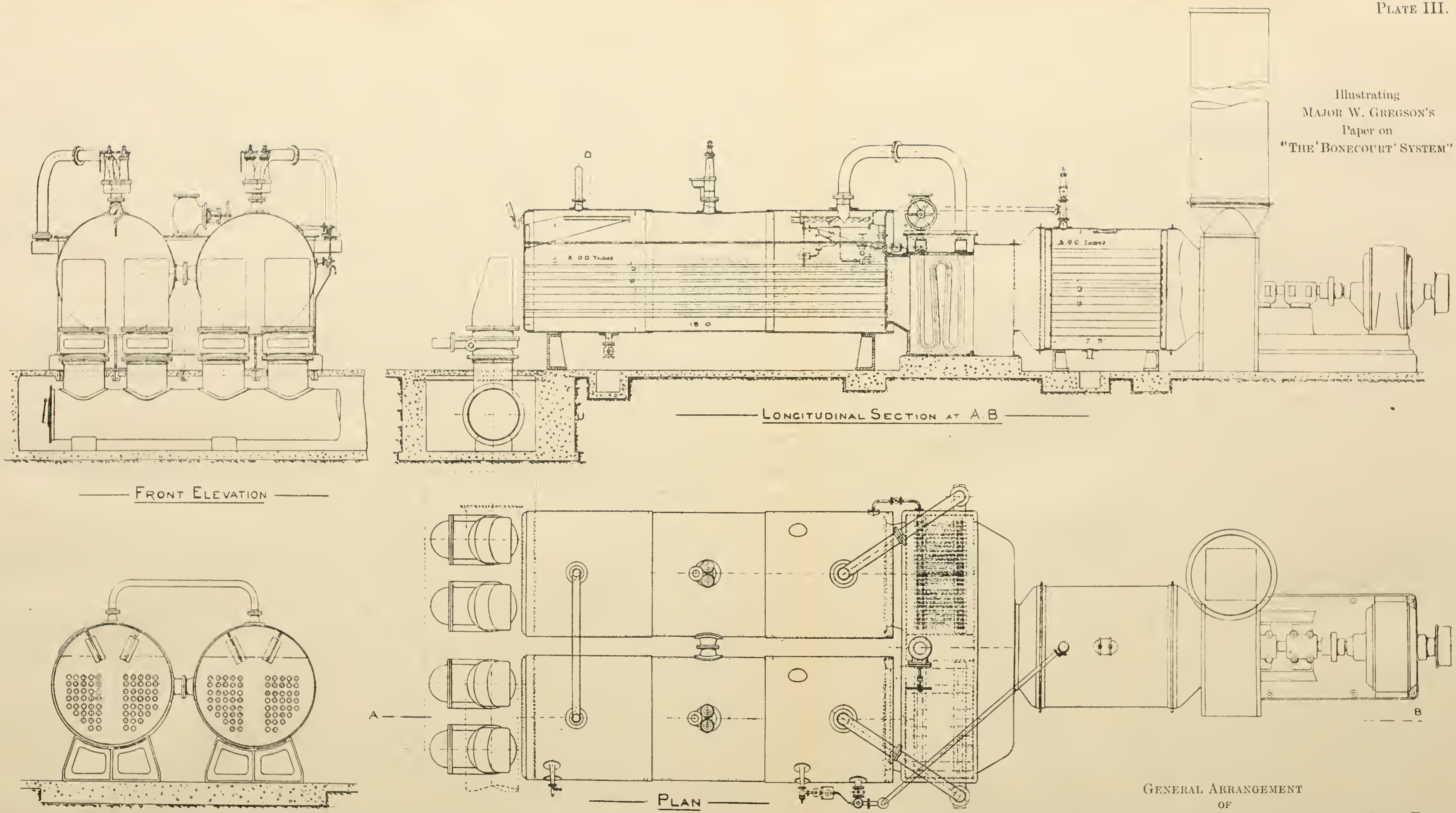
Illustrating
Major W. Gregson's
Paper on
"The 'Bonecourt' System"





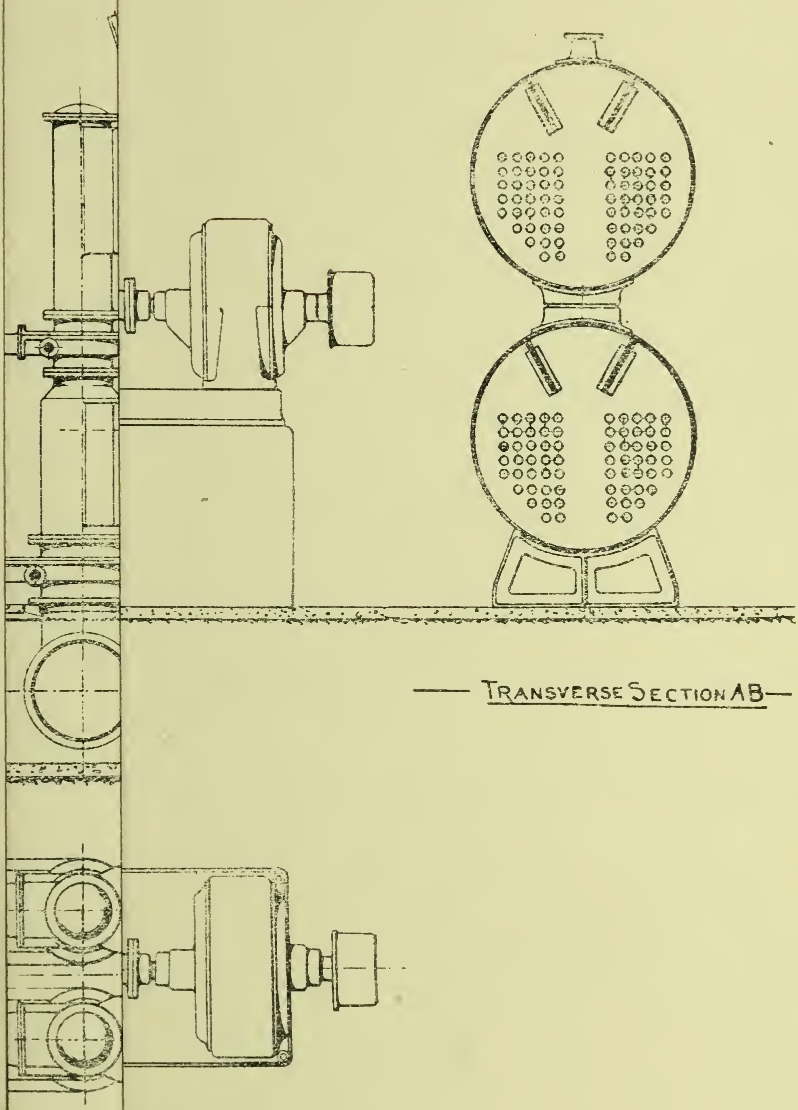

al Arrangement
of
Patent Gas Fired Double Drum Boiler
nomiser and Induced Draught Plant

Illustrating
Major W. Gregson's
Paper on
"The 'Bonecourt' System"



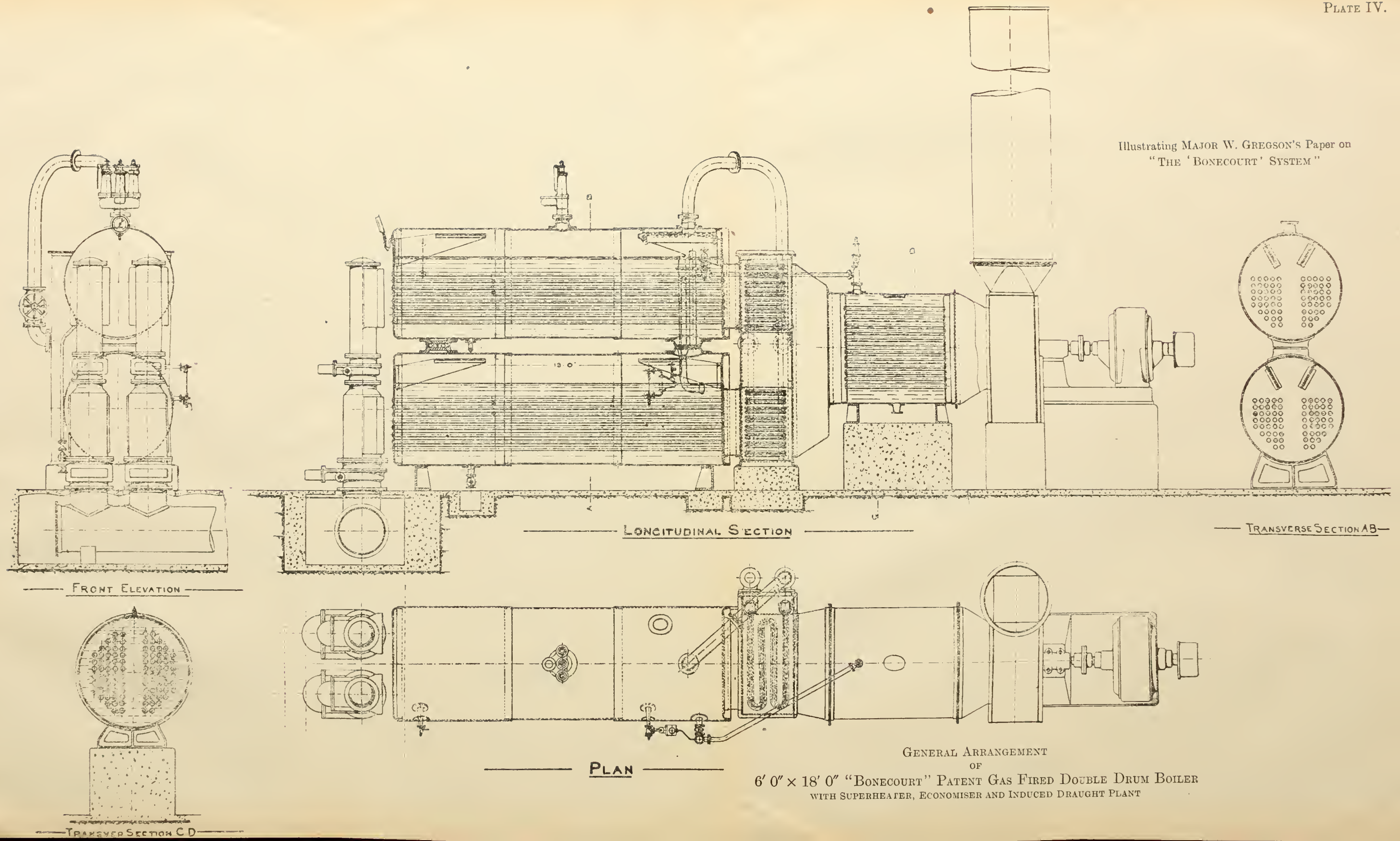

General Arrangement
of
6′ 0″ × 18′ 0″ "Bonecourt" Patent Gas Fired Double Drum Boiler
with Superheater, Economiser and Induced Draught Plant

Illustrating MAJOR W. GREGSON'S Paper on
"THE 'BONECOURT' SYSTEM"




UBLE DRUM BOILER
UGHT PLANT

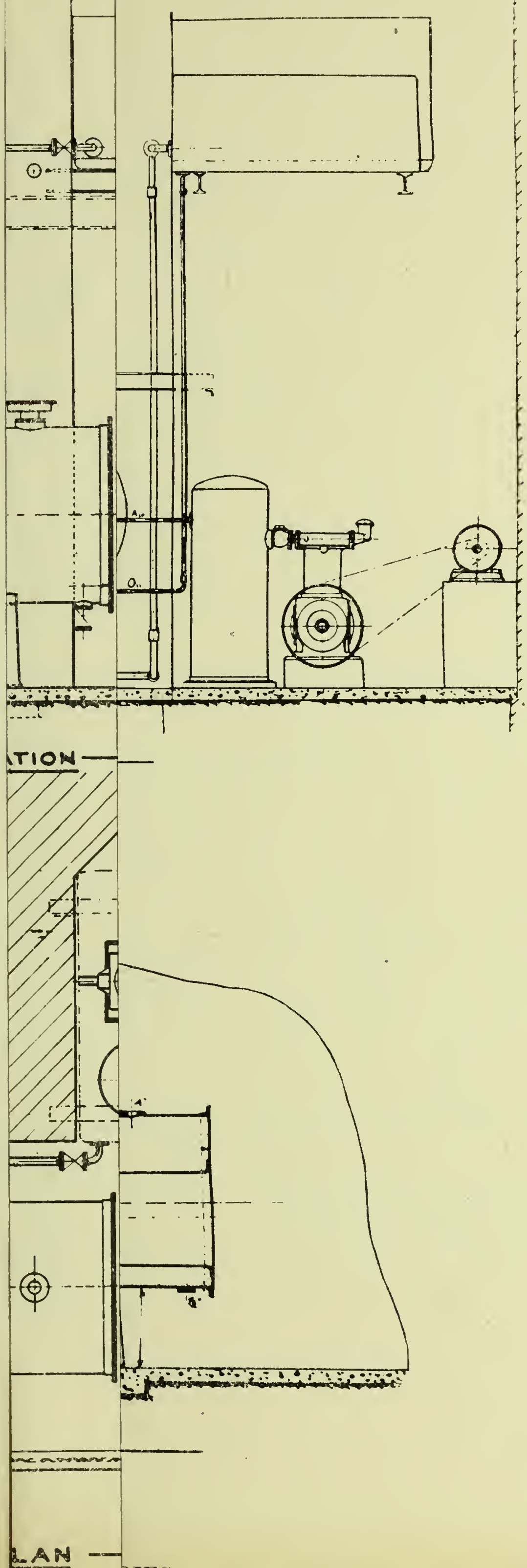
Illustrating Major W. Gregson's Paper on
"The 'Bonecourt' System"




General Arrangement
of
6' 0" × 18' 0" "Bonecourt" Patent Gas Fired Double Drum Boiler
with Superheater, Economiser and Induced Draught Plant

Plate V.

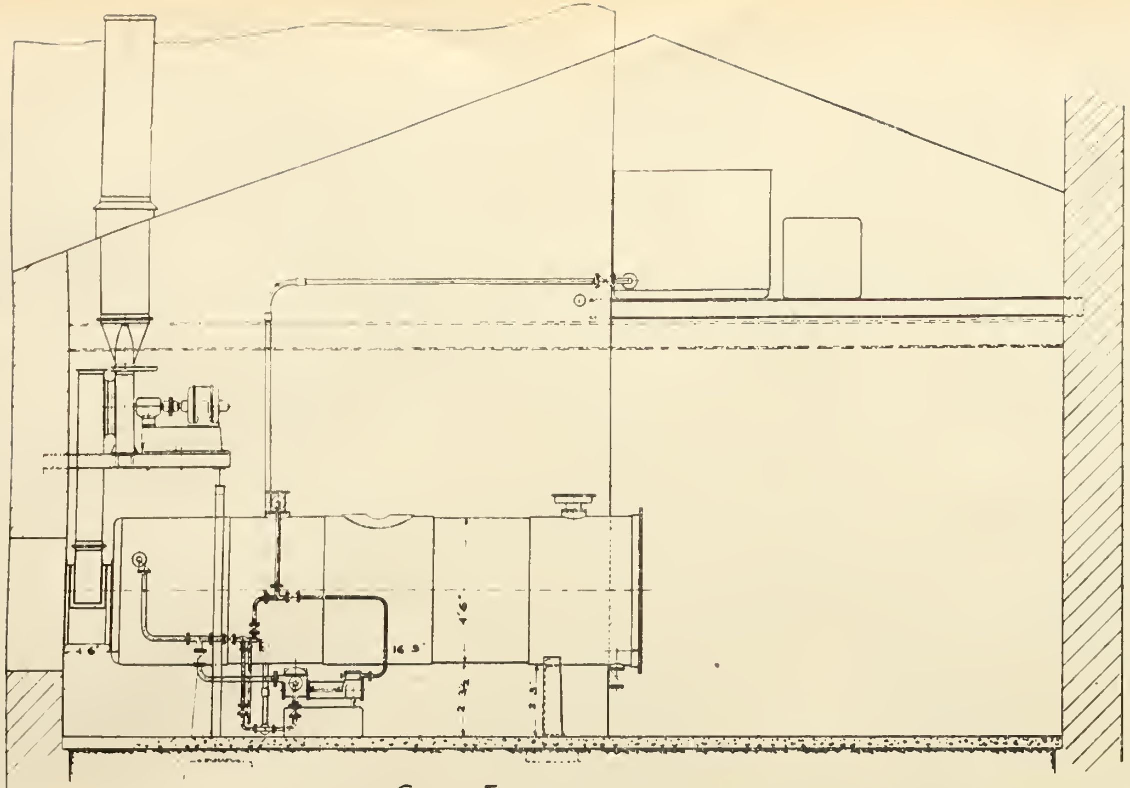
rating Major W. Gregson's
Paper on
ie 'Bonecourt' System"



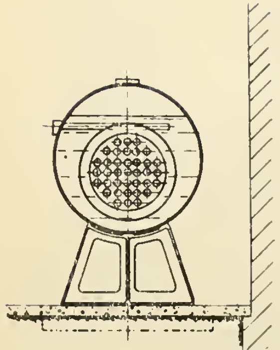

RIES

PLATE V.

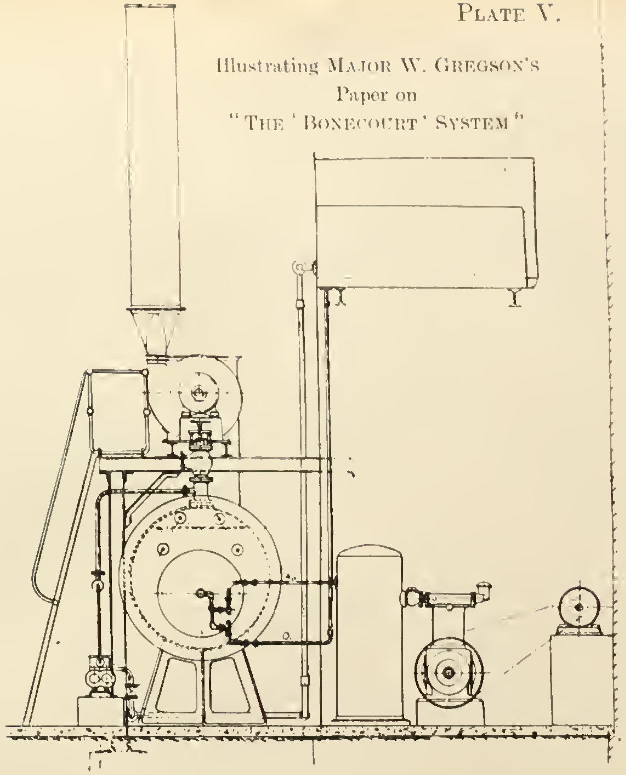
Illustrating MAJOR W. GREGSON'S
Paper on
"THE 'BONECOURT' SYSTEM"



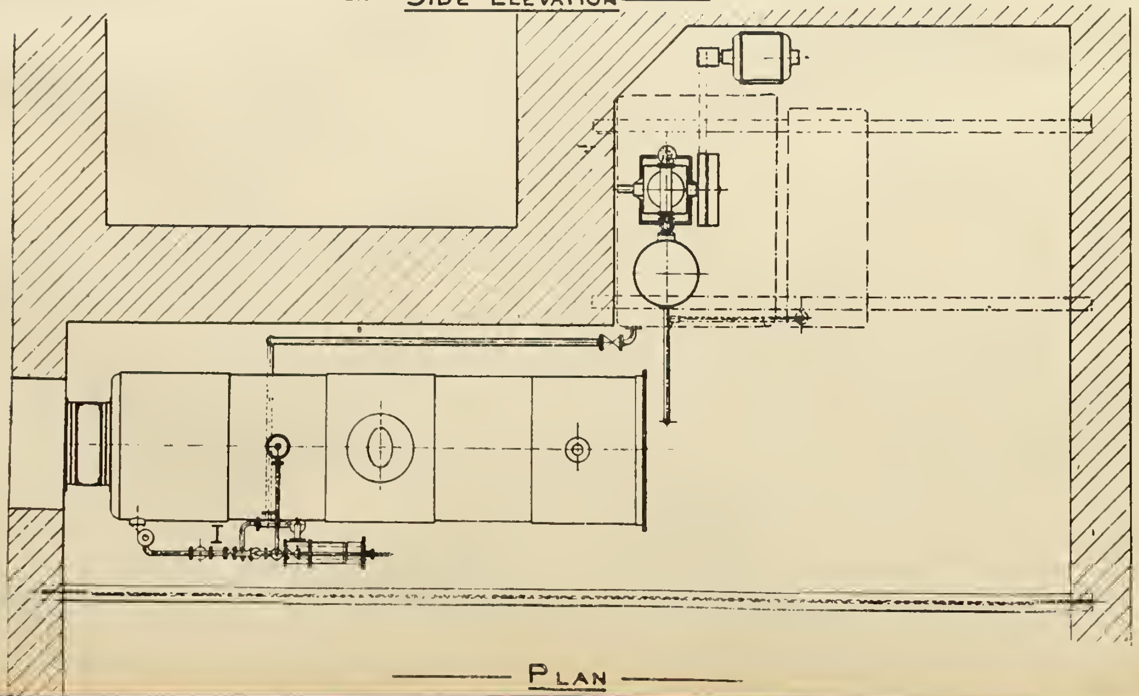
SIDE ELEVATION



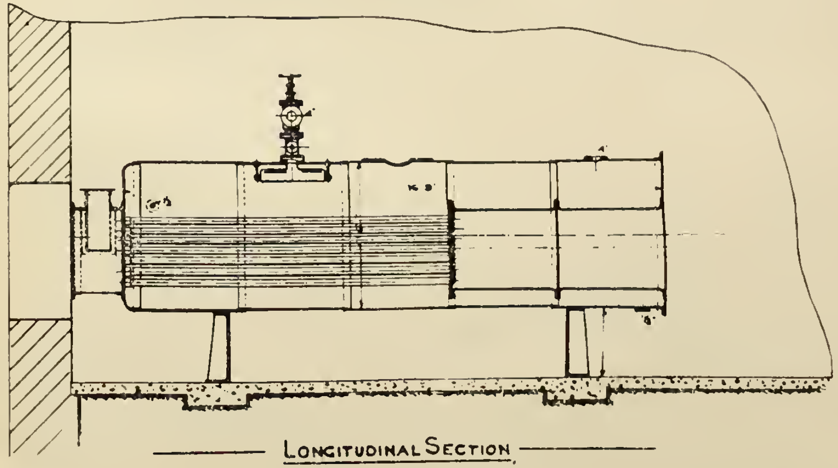
TRANSVERSE SECTION A B



FRONT VIEW



PLAN



LONGITUDINAL SECTION

GENERAL ARRANGEMENT OF
4′ 6″ × 16′ 9″ "BONECOURT" OIL FIRED BOILER AND ACCESSORIES

commercial sense, which means going into the question of the actual costs of steam raising. Major Gregson.

I have already made one statement in my paper in which I gave a comparison between coke-oven gas and direct coal-firing, but in this particular instance I only considered fuel costs. I therefore insert a short table (Table 'A') showing relative boiler operation costs based on a continuous rating of 10,000 lbs. of steam per hour from and at 212° F. for one year, i.e. twenty-four hours per day and 365 days in the year. This particular table is based on an actual case investigated in the North of England, where the choice lay between utilising coke-oven gas at 1*s.* per 1000 cubic feet (it was a case where the coke-ovens supplied their surplus gas to the local gas-works) or second quality coal of 12,000 B.T.U.'s per lb., which could be taken at 33*s.* per ton delivered to the boilers. In this particular example the actual fuel cost is higher in the case of the 'Bonecourt' boiler than in the case of the Lancashire boiler, but the saving due to labour and also the saving on depreciation and interest due to lower capital cost in the case of the 'Bonecourt' boiler installation more than balanced the extra fuel cost.

Last week end I happened to see an extract from a paper recently read before the Society of Chemical Industry on the subject of 'More Economical Utilisation of Coke-Oven and Blast-Furnace Gas for Heating and Power.'

The authors have gone to considerable trouble in getting out relative costs for the generation of electricity from gas fuel, basing their arguments on large gas engines with an average efficiency of 25 per cent. compared with turbines and boilers with an average efficiency of 15 per cent.; on these figures the costs of generating electricity by boilers and turbines worked out at approximately 25 per cent. higher than in the case of the gas-engine plant, the figures quoted

Major Gregson.

in the paper in question for the cost of generating one B.T.U. of electricity from blast-furnace gas using a gas engine being ·306*d*., this amount in the case of boilers and turbines being increased to ·384*d*.

I should, however, like to make a few comments here. It is an accepted fact that modern gas engines will give one shaft h.p. for every 10,000 B.T.U.'s in the gas; in fact, this figure has been reduced to 9500 in several officially noted tests. The figure of 10,000 gives an overall thermal efficiency from gas energy to shaft energy of 25·5 per cent. On the other hand, numerous examples are also quoted of turbines giving one shaft h.p. for 10,000 B.T.U.'s in the steam, and in the case of the Ljungström turbine (which is specially designed for high pressures and high steam temperatures) an example is quoted where a 5000 k.w. turbine set, working at a steam pressure of 300 lbs. per square inch, and with a total steam temperature of 750° F., gave a steam consumption of 6·5 lbs. per shaft h.p. per hour. This works out at 9000 B.T.U.'s per shaft h.p. hour from the steam. Assuming a 'Bonecourt' boiler working at an efficiency of 90 per cent. were employed with such a turbine, this figure would become 9000 divided by ·9, equals 10,000 B.T.U.'s (as gas energy) per shaft h.p.; in other words, the combined efficiency of turbine and boiler is now equal to that of the gas engine, i.e. 25·5 per cent., which equalises the fuel consumption of the gas engine and of the turbine-'Bonecourt' boiler combination. Presumably, the above figure of 9000 B.T.U.'s as steam per shaft h.p. represents ideal conditions, but it seems possible to obtain a shaft h.p. for 10,000 B.T.U.'s under normal industrial conditions, hence coupling this up to a 'Bonecourt' boiler of 90 per cent. efficiency means one shaft h.p. for just over 11,000 B.T.U.'s in the gas, being a thermal efficiency of 23 per cent. I have in my mind in this connection a 1000 k.w. set working at a steam pressure

of 210 lbs. per square inch with a total steam temperature of 710° F. which is capable of doing this. **Major Gregson.**

We therefore come down to the fact that a suitably designed turbine combined with a 'Bonecourt' boiler will, under excellent conditions, equal the thermal efficiency of a big gas engine, and under ordinary conditions will only be a fraction behind. This deficit is more than balanced by the following advantages of a turbine and boiler installation.

(*a*) The first cost of the plant is considerably lower than the first cost of the gas-engine proposition, hence the annual allowance for depreciation and interest on capital is lower.

(*b*) The cost of maintenance of the steam plant would be lower than that of the gas-engine plant, owing to the greater mechanical simplicity of the former.

(*c*) In the case of units working on blast-furnace gas, the cost of cleaning the gas would be less in the case of the boiler plant, as the boiler only requires partially cleaned gas, whereas cleaning must be carried to a much higher degree for gas-engine work.

Regarding the use of blast-furnace gas in the 'Bonecourt' boiler I should like to mention that experiments carried out by the Company some time ago show that there is no difficulty in using this gas, preheated air being an advantage when long tubes are used. Starting up is of necessity slower than in the case of a richer gas, as it is necessary to feed the gas in slowly at the commencement of the run, and gradually speed up as the temperature of the tubes and boiler rises, otherwise the flame is liable to be quenched

Blast-furnace gas as usually delivered to boilers suffers from variations in pressure, and for really efficient working it would appear advisable to install suitable apparatus for delivering the gas at constant pressure, but this is by no means a necessity, as even should the supply of gas fall off entirely

Major Gregson.

at times, the flame can always be re-formed by pilot jets running on other gas.

I should like to revise one point dealing with the construction of 'Bonecourt' boilers. I stated in my paper that the tube plates are sometimes stayed by stay tubes, but would point out that this only applies to the older boilers, present practice being to use either gusset stays, longitudinal stays in the steam space, or stiffeners, according to the requirements of the particular construction, and in all cases the tubes are bell-mouthed 10 per cent. of their diameter.

Table 'B' represents some tests recently carried out by an independent firm on a 'Bonecourt' boiler working on Mond gas. It will be noted that an overall efficiency of approximately 85 per cent. was obtained, the boiler not being lagged and no economiser being fitted. With gas of such low calorific value and low hydrogen content, these figures are extraordinarily good ; naturally, owing to the larger volume of gaseous products obtained per pound of steam evaporated from low grade gas, the efficiencies are not so high as obtainable with rich gases such as coke-oven gas, furthermore the addition of an economiser means that the final temperature of the gases can be reduced approximately a further 100° C., again adding to the thermal efficiency (overall) of the boiler.

Lastly, I should like to mention the fact that the 'Bonecourt' waste-heat boiler has shown that a modern gas-works can do away with coal-fired boilers entirely for steaming their retorts and for auxiliary work. In a case in point, a 'Bonecourt' boiler is giving double the steam output that they actually require for their own immediate needs, even though it is working on natural draught, and hence has a higher outlet temperature than is usually worked to on waste-heat propositions, owing to the necessity for leaving sufficient draught in the chimney to operate the retorts.

There can be no doubt that if a large proportion of our

industrial concerns were seriously looked into with a view to the utilisation of all their waste heat, and the conversion of same to steam and power, that the coal-fired boiler which in many cases is practically alongside furnaces and other industrial apparatus belching forth waste heat could be totally eliminated, as all steam and power requirements could be met by a suitably designed waste-heat boiler installation. **Major Gregson.**

TABLE 'A.'

Cost of Steam Production for a *continuous* rating of 10,000 lbs. of steam per hour (from and at 212° F.) for one year—24 hours per day and 365 days in the year.

| | 'Bonecourt' Boiler. | Lancashire Boiler. |
|---|---|---|
| | Coke-oven Gas of 500 B T.U.'s nett at 1*s*. per 1000 Cubic Feet. | Coal of 12,000 B.T.U.'s per Lb. at 33*s*. per Ton delivered to Boilers. |
| Fuel cost per annum assuming 90 per cent. 'Bonecourt' efficiency and 60 per cent. Lancashire boiler efficiency (including economisers) . . . | £9450 | £8650 |
| Wages (stoker) one per shift at 1*s*. 6*d*. per hour—neglecting extra pay over week ends. Including labour for ash removal . . . . . . | Nil | 655 |
| Depreciation: 10 per cent. on capital cost. 'Bonecourt'—approx. £2000; Lancashire—approx. £4200. (Complete with foundations, chimney, settings, &c., and including erection in each case.) Capital cost includes economisers and superheaters and in case of 'Bonecourt' outfit complete induced draft plant . . . . | 200 | 420 |
| Interest on capital at 7 per cent . . | 140 | 294 |
| Electricity for fan at $\frac{3}{4}d$. per unit . . | 184 | Nil |
| Total per Annum . . . . | £9,974 | £10,019 |

Neglecting maintenance charges, which will be approximately equal.

TABLE 'B.'—TESTS ON 'BONECOURT' BOILER FIRED ON MOND GAS.

Major Gregson.

Outputs varying from approximately full load to quarter load. Boiler was designed for a maximum output of 2000 lbs. of steam per hour from and at 212° F. Boiler was *unlagged* during the tests, and was not fitted with an Economiser.

| | | Test 1. | Test 2. | Test 3. | Test 4. |
|---|---|---|---|---|---|
| Gas pressure in inches of water | | 1·38″ | 0·985″ | 0·394″ | 0·118″ |
| Suction . . . . . | | 7·7″ | 6·3″ | 3·15″ | 0·985″ |
| Nett calorific value of gas in B.T.U.'s per cubic foot . | | 147·9 | 143·5 | 143·3 | 131·7 |
| Products of combustion | $CO_2$ | 14·8% | 15% | 15·2% | 15·2% |
| | $O_2$ | 1·4% | 2·2% | 1·2% | 1·1% |
| | CO | 0·6% | 0·4% | 0·6% | 0·5% |
| Heating surface in sq. ft. . | | 140 | 140 | 140 | 140 |
| Evaporation in lbs. from and at 212° F. per hour, boiler unlagged . . . . | | 2160 | 1890 | 1200 | 590 |
| Evaporation per sq. ft. of heating surface in lbs. with boiler unlagged . . . | | 15·4 | 13·5 | 8·5 | 4·2 |
| Temperature of products leaving boiler . . . | | 255° C. | 243° C. | 210° C. | 175° |
| Thermal efficiency without economiser . . . | | 84% | 84% | 86% | 86% |

The hydrogen content in the Mond gas averaged 22·8 per cent.

Mr. W. A. Chamen.

Mr. W. A. CHAMEN said they had listened to a most interesting and instructive paper, and he hoped many of them would have much to say about it when they had further opportunity of studying it. Most of them thought a great advance was made many years ago when they got water-tube boilers, which had the advantage when there was encrustation of being able to bore out the tubes and get at the deposit. In the 'Bonecourt' boiler any encrustation would be on the outside of the tubes; and the question which they would require to go fully into was

whether they would get trouble from this accumulation of scale on the outside of the tube. This in large boilers might be very difficult to remove. He wondered whether the figures that Mr. Gregson had put before them were all a dream. (Laughter.) Of course they had done a lot of wrong things in the past, and they might be excused if they wished they could wait a year or two to see if Mr. Gregson's figures were realised in practice. **Mr. W. A. Chamen.**

Mr. W. H. REYNOLDS said he hoped to contribute to a discussion of the paper at a future meeting; but he should like now to ask Mr. Gregson whether he claimed to raise a full head of steam from cold feed to 100 lbs. pressure in twenty minutes. **Mr. W. H. Reynolds.**

Major GREGSON: I think I said thirty. **Major Gregson.**

Mr. REYNOLDS said even in that case he was sure they would find that the boiler suffered tremendously. As an old marine engineer, with service in the Royal Navy and the Mercantile Marine, he knew from experience of the old Scotch multitubular boiler and similar types what would happen if they rushed up to a full head of steam from cold water like that. Mr. Gregson might answer that his method of firing made all the difference, but there was no doubt that if he attempted to raise steam on a boiler of that type, although it were only 6 feet in diameter, up to a pressure of 100 lbs., and repeatedly did this, metaphorically speaking, very soon that boiler would not hold bricks let alone water. (Laughter.) **Mr. Reynolds.**

Invited by the President to contribute to the discussion, Professor FREDERIC BACON said he had read the paper with great interest, and doubtless it would be keenly discussed at the next meeting. It was impossible to deal in a cursory manner with a type of steam generation claiming such high efficiency as that shown in the paper. **Professor Frederic Bacon.**

Mr. ROBERT JAMES said the paper gave promise of a useful discussion at the next meeting. He was only sorry that the **Mr. Robert James.**

Mr. Robert James.

boiler which was on order for the School of Mines at Treforest had not arrived. A point that was probably in Mr. Reynolds' mind when he spoke of what might happen if they raised steam very rapidly had reference to grease on the water—a possible source of trouble. There was also the question of bad water. Then he (Mr. James) was looking forward to reading the further information promised regarding relative costs, depreciation, etc.

The President.

The PRESIDENT said although the hour was late they had had an interesting discussion. They had not had proper time to digest all that was in the paper, and he would adjourn its consideration to the next meeting, which would be held on September 30 at Swansea, in which locality there were large users of steam, and a full discussion ought to be forthcoming. Gas-firing of boilers was certain to develop in South Wales with the increase of by-product coke-ovens that was contemplated at several collieries ; so that Mr. Gregson's paper was opportune. He moved a cordial vote of thanks to Mr. Gregson, who he hoped would be able to attend the Swansea meeting. (Applause )

# PROCEEDINGS.

## Joint Meeting of the Fuel Economy Committee and South Wales Institute of Engineers, held on Thursday, August 26, 1920.

A JOINT meeting of the Fuel Economy Committee of the British Association for the Advancement of Science and the South Wales Institute of Engineers was held at the Institution, Cardiff, on Thursday, August 26, 1920.

The chair was occupied by the President of the Institute, Mr. J. DYER LEWIS, H.M. Divisional Inspector of Mines.

## The Economics of the South Wales Coal-field.

BY HUGH BRAMWELL, O.B.E.

Mr. BRAMWELL gave a synopsis of a paper on 'The Economics of the South Wales Coalfield.' The following is the paper *in extenso*. **Mr. Bramwell.**

# THE ECONOMICS OF THE SOUTH WALES COAL-FIELD.

By Hugh Bramwell.

# THE ECONOMICS OF THE SOUTH WALES COAL-FIELD.

By Hugh Bramwell.

This Paper does not enter into detailed statistics, but draws attention to some of the more or less special features of the South Wales coal-field, which have created or tended to create its economic conditions.

To state the case it is, however, desirable to give some comparative figures, and for this purpose the Board of Trade returns, the evidence given before the Sankey Commission, and other sources are drawn upon.

(1) *Output and Number of Persons Employed.*—The following table is taken from the Board of Trade's last return under the Coal Mines Regulation Acts:—

| | Persons employed. | | Output. | | Output per annum per person employed. | |
|---|---|---|---|---|---|---|
| | South Wales. | United Kingdom. | South Wales. | United Kingdom. | South Wales. | United Kingdom. |
| | | | Tons. | Tons. | Tons. | Tons. |
| 1913 | 233,134 | 1,127,890 | 56,830,072 | 287,411,869 | 244 | 255 |
| 1914 | 234,117 | 1,133,746 | 53,879,728 | 265,643,030 | 230 | 234 |
| 1915 | 202,655 | 953,642 | 50,452,600 | 253,179,446 | 249 | 265 |
| 1916 | 214,100 | 998,063 | 52,080,709 | 256,348,351 | 243 | 257 |
| 1917 | 219,718 | 1,021,340 | 48,507,902 | 248,473,119 | 221 | 243 |
| 1918 | 218,853 | 1,008,867 | 46,716,535 | 227,714,579 | 213 | 226 |
| 1919 | 257,613 | 1,191,313 | 47,522,306 | 229,743,128 | 184 | 193 |

It will be seen that Wales produces 20 to 21 per cent. of the country's output ; that the number of persons employed

in 1919 is 10 per cent. in Wales and 6 per cent. in the United Kingdom more than were employed in 1913; and that the production in Wales in 1919 is 16 per cent. and in the United Kingdom 20 per cent. less than in 1913, notwithstanding the increased number of persons engaged.

Combining these figures, it follows that the annual production per person employed has gone down by 24·6 per cent. in Wales, and by 24·3 per cent. in the United Kingdom, between 1913 and 1919.

It will also be noted that the production per person employed is about 5 per cent. less in Wales than in the United Kingdom as a whole, notwithstanding the fact that the mines in Wales are open for work for six days in the week; whereas the opportunity for six days' work a week is by no means general but is rather the exception, in other coal-fields. Further, it should be recorded that the coal seams in Wales are on the average thicker than those in many of the other coal-fields.

(2) *The Earnings of the Persons Employed.*—The following figures are taken from the evidence given before the Sankey Commission:—

EARNINGS PER SHIFT.

| | South Wales. | | United Kingdom. | |
|---|---|---|---|---|
| | Adults, underground only. | All persons, underground and surface. | Adults, underground only. | All persons, underground and surface. |
| | *s.* *d.* | *s.* *d.* | *s.* *d.* | *s.* *d.* |
| 1914 | 7 8·20 | 6 9·22 | 7 6·89 | 6 5·64 |
| 1918 | 15 7·27 | 13 7·55 | 14 7·92 | 12 5·28 |

From this it will be seen that in 1914 the earnings in South Wales were 4 per cent. to 5 per cent. higher than those in the coal-fields of the United Kingdom, and in 1918 the difference was 8 per cent. to 9 per cent. The Welsh earnings have

increased between the years named by 101 per cent., whereas the United Kingdom earnings have risen by 92 per cent. It should be remembered that these are actual results, and include the effect of the reduced amount of work done, as noted in the preceding heading.

Since these figures were ascertained the mine workers have received in addition what is known as the Sankey Wage, viz. 2*s*. per day for adults, and 1*s*. per day for boys under 16, and the more recent increase of 20 per cent. on their earnings (20 per cent. on earnings less war wage and Sankey wage), with minimum advances of 2*s*., 1*s*., and 9*d*. per day, depending on age. This is, however, incidental; the point to which attention is drawn is that the workers in the Welsh coal-field receive about 9 per cent. higher wages than do the workers in the coal-fields of the United Kingdom generally. The recent figures given by the Board of Trade fully substantiate this.

(3) *Cost of Production.*—The following figures are taken from the published records of the South Wales Coal Owners' Association and the official records of the Board of Trade :—

| | Cost per ton—Wages only. | |
|---|---|---|
| | South Wales. | United Kingdom. |
| | *s.* *d.* | *s.* *d.* |
| 1887 | 3 6·00 | — |
| 1889–1893 | — | 4 7·16 |
| 1892 | 5 4·00 | — |
| 1899–1903 | — | 5 5·52 |
| 1902 | 6 7·00 | — |
| 1913 | — | 6 4·01 |
| 1914 | 8 1·00 (7 months to July) | 6 2·92 |
| 1915 | — | 7 9·58 |
| 1916 | — | 9 9·12 |
| 1917 | — | 10 5·53 |
| 1918 | — | 13 2·80 |
| 1919 | 23 0·00 | — |
| 1920 | (May) 27 0·00 | 22 8·00 |

The figures for May 1920 include the recent 20 per cent. advance, which works out for the United Kingdom at 2*s*. 10*d*. per ton.

The gross cost of production as recently published by the Board of Trade for three months ending March 31, 1920, covering wages, stores, management, royalties, etc., is 29*s*. 6·72*d*. per ton for the United Kingdom, whilst that for Wales only is 36*s*. 5·98*d*. per ton, a difference of 7*s*. per ton, wages and pitwood being the two chief points of difference, as shown by the figures below.

THREE MONTHS ENDING MARCH 31, 1920.

| | South Wales. | | | United Kingdom. | | |
|---|---|---|---|---|---|---|
| | *s.* | *d.* | | *s.* | *d.* | |
| Wages . . . | 27 | 1·79 | per ton | 22 | 8·50 | per ton |
| Pitwood and stoves | 6 | 0·66 | ,, | 4 | 6·99 | ,, |
| Other costs and royalties | 3 | 3·53 | ,, | 2 | 3·23 | ,, |
| | 36 | 5·98 | ,, | 29 | 6·72 | ,, |

(4) *Disposal of Output.*—The exports from South Wales and from the United Kingdom are as below:—

| | South Wales. | United Kingdom. |
|---|---|---|
| 1913 . . . | 29,875,916 | 73,400,118 |
| 1914 . . . | 24,475,551 | 59,038,880 |
| 1915 . . . | 18,601,896 | 43,534,560 |
| 1916 . . . | 17,417,707 | 38,351,553 |
| 1917 . . . | 19,893,015 | 34,995,787 |
| 1918 . . . | 17,000,834 | 31,752,904 |
| 1919 . . . | 20,229,802 | 35,249,578 |

These are the figures for foreign cargo shipments, and exclude coastwise shipments and bunker coal both foreign and coastwise.

Comparing these figures with those as to output in heading (1), it will be seen that in 1913 Wales exported to foreign

countries 52 per cent. of its production, and in 1919 42 per cent., whereas the United Kingdom exported 25 per cent. and 15 per cent. of its production for the same years.

Since these figures were ascertained the home requirements of the country have so increased that it is estimated that not more than 10 per cent. of the country's production will be available for export.

Having thus stated the position, one seeks for the underlying causes.

*General.*—The economic conditions of any coal-field are largely the accumulative results of a few outstanding characteristics, such as—

(1) The geological and physical features.
(2) The position of the coal-field in relation to the seaboard.
(3) The nature and qualities of the coal produced.
(4) The competition with other coal-fields in the United Kingdom and abroad.

A description of the coal-field,[1] with a plan showing the areas from which the several classes of coal are chiefly got, is given in the handbook of the British Association. The plan is reproduced here. See Plate I.

The coal-field is a typical geological elongated basin some 90 miles E. and W. long, with a maximum width N. and S. of some 16 miles. It lies practically parallel to the seaboard of the Bristol Channel, and is served by several easily accessible seaports. The surface is cut by denudation into deep narrow valleys running generally N. and S. across the field—railway access N. and S. in the direction of the sea is thus easy, and short access E. and W. across the line of valleys is difficult. The average distance from pit to port is only

[1] Vide Handbook of The British Association for the Advancement of Science, Cardiff Meeting, August 1920.

some 15 to 20 miles. The Taff Vale Railway Company's average length of haul (coal, coke, and patent fuel) is 12·93 miles.

The coal-field yields four typical classes of coal, viz. :—

(1) Bituminous coal,
(2) Steam coal,
(3) Smokeless steam coal,
(4) Anthracite,

all grading one into the other, each in its class of high quality, and commanding a relatively high price in competition with other coal-fields.

Broadly, each class comes from different areas of the field, varied, however, within limits at any particular place, according to the vertical geological horizon of the seam from which the coal is worked. The special quality of the steam coal has led to its world-wide use for railways and steamships.

The export trade of South Wales is thus a natural result of the qualities of the coal and the position of the coal-field.

*The Coal Seams.*—From a mining standpoint the coal seams may be divided into four more or less well-defined zones, viz. :—

(1) An upper series including the Mynyddislwyn and Llantwit seams, existing in limited areas as geological outliers, and associated with comparatively thin beds of sandstone and sound shales. Largely worked in the past, and in the eastern part of the field largely exhausted.

(2) The Rhondda series of seams lying immediately below the massive Pennant sandstone and associated generally with thick beds of sandstone (rock) and few beds of shale. Largely worked in the past and now being worked. In the eastern part of the coal-field somewhat exhausted.

(3) A series of generally thin seams, including the Pentre

and Abergorki seams, lying between the Rhondda seams and the steam coals, which have only been worked to a limited extent in places where one or more of them happen to be well developed.

(4) The great steam coal seams which in the western area also form the chief source of the anthracite coal production, associated with friable and easily weathered shales and only a few thin beds of sandstone.

*Mining.*—The different character of strata associated with the several seams to a great extent determines the methods of mining and economic conditions.

At present the steam coal series of seams, being the most important and extensively worked, give the coal-field its special characteristics and really determine its present economic position in relation to the other coal-fields of the country. The characteristics of the other seams mentioned may be looked upon as exceptional and not typical.

The following remarks therefore apply to the mining of the steam coal seams, as characteristic of the coal-field.

*Pressure or Squeeze.*—The outstanding mining feature is summed up in the word 'squeeze.' In mining 'extraction' is followed by 'subsidence,' with the resulting crush and squeeze on the excavated areas, and on the roads maintained through such areas. That is a general proposition, common to all coal-fields.

In most coal-fields this effect is usually confined to the excavated areas and their immediate surroundings. In most coal-fields roads driven in the solid coal or in the undisturbed strata usually stand intact, and roads maintained through excavated areas soon come to a state of rest. The characteristic of South Wales mining is that roads driven in the solid coal or in undisturbed measures do not generally stand intact, and are frequently more difficult and expensive to maintain than roads

passing through excavated areas. The whole of the strata in Wales appears to be under compression, and being comparatively soft, an opening made in it, even of small dimensions, at once commences to squeeze in and close up. It is this general characteristic that renders Welsh mining on the whole different from that in other coal-fields. In Wales this 'squeeze' is general, and it is the exception to find parts more or less free from it. In other coal-fields it is not general, and is the exception rather than the rule (except in those parts where minerals have been extracted, and then only for a limited time).

In Wales the extraction of the coal seam tends to provide space for expansion of the associated measures, and thus to reduce or remove the 'squeeze,' notwithstanding the subsidence caused.

This feature has led in mining to the almost universal adoption of complete extraction in one advancing face, followed by complete stowing.

There are three physical features in South Wales which may possibly account for this state of compression.

1st. The more or less detached mountain masses forming the surface, the weight of which is supported by the measures in which mining is chiefly carried out.

2nd. The soft and friable nature of the strata associated with the coal seams chiefly worked.

3rd. The heavy geological thrust from the south to which the coal-field has been exposed, as evidenced by the upturned edges of the southern outcrops and the large anticlinal fold running parallel to the southern crop at a distance of some 5 or 6 miles for nearly its whole length.

The economic result is shown by the higher cost of production due to the heavy cost of maintenance of the mines in repairing labour, and the pitwood necessary for safe working.

The result of this feature is also that whilst in other coal-fields it is sometimes found economical to drive out roads in the solid before complete extraction is commenced, or even to extract on a retreating system of mining, in South Wales such a type of work is practically unknown, and where for some special reasons it has been attempted, the result has been quite unfavourable and found to be commercially impracticable. The roads stand best in South Wales where the minerals have been extracted, and where relief of pressure by subsidence has been effected.

Pressure in time completely closes the excavated areas in South Wales, so much so that practically no open spaces other than the roadways remain. In other coal-fields this is not so general, and excavated areas are frequently partially open or contain a proportion of open space in which gas may accumulate. A goaf or gob giving off gas is unusual in South Wales—it is generally quite tight.

*Stowing.*—These conditions have tended to develop a system of complete stowing with roof bending, as distinct from the system common in other coal-fields of pack-walls with intermediate more or less open spaces in which the roof is intentionally allowed and encouraged to break.

The practicability of economically working on complete stowing presupposes a readily available quantity of waste material for the purpose.

There is frequently (almost generally) interbedded with the steam coal seams in Wales, beds of soft, friable bituminous shale (' rashings '), which with the material from roadway enlargement provide the stowing material.

In mining it is difficult (sometimes impossible) to prevent the ' rashings ' from mixing with a certain proportion of small coal, and this mixture of coal and shale, generally running at 30 or 40 per cent. of 'dirt,' is used for stowing the excavated spaces.

## Loss of Small Coal.

One of the features of the steam coal mining that is frequently referred to is the loss to the country of small coal that is left underground.

The practice has arisen from economic conditions, viz :—

1. The difficulty just mentioned of keeping the small coal reasonably clean and free from 'dirt.'

2. The difficulty in past years in disposing commercially of the 'dry' 'non-bituminous' small.

3. The consequent customary method of paying the coal getters on the basis of large clean coal produced, with the object of encouraging the maximum production of the most valuable product.

4. The practice of completely stowing the 'gob,' or space, from which the coal has been extracted.

*Quantity of Small Coal left Underground.*—Very various statements as to this have from time to time appeared, varying from 5 to 25 per cent., with extreme instances. Generally these are mere guesses from observation in particular cases. As a matter of fact, there are no real means of measuring the quantity left underground, and there are very few recorded attempts at careful estimation even in particular cases, and none, as far as is known, for the coal-field as a whole.

The proportions of large and small coal sent to bank at different periods are some guide as to the amount of small coal left underground. Assuming that the seams worked in the coal-field are more or less the same at different periods, the inference from the records of the Coal Owners' Association given below point to the probability that the loss is becoming less and less.

| | Large. Per cent. | Small. Per cent. | Total. Per cent. |
|---|---|---|---|
| 1887 year . . | 81 | 19 | 100 |
| 1897 ,, . . | $77\frac{1}{2}$ | $22\frac{1}{2}$ | 100 |
| 1908 ,, . . | 72 | 28 | 100 |
| 1918 ($\frac{1}{4}$ year) . | $67\frac{1}{3}$ | $32\frac{2}{3}$ | 100 |

Some of the estimates as to the loss of small coal have been given as a percentage on the coal raised, others on the contents of the seam. Such are incomparable. The latter is the more useful basis. Three actual instances are recorded by the Royal Commission on Coal Supplies, 1903, where in seams where small coal is 'gobbed' the gross get fell short of the calculated contents of the seam by 13·4 per cent., 10·2 per cent., and 11·2 per cent. Similar seams where all the coal was sent out gave a difference of 3 per cent. to 5 per cent., thus pointing to a loss through small coal being thrown back of about 7 per cent.

The small coal mixed with small dirt has a useful purpose in the complete stowing of the gob, which in its turn enables very complete total extraction of the mineral contents of the seam. The net result, as found by the Royal Commission on Coal Supplies, 1903, is that the loss in working in South Wales, where it is the practice to leave some of the small coal underground, is no greater than the loss in working in several other coal-fields where no small coal is left underground, the reason to account for this being that complete stowing of the gob tends to promote complete extraction of the seam contents.

Further, the system of paying the coal getter on the produce of clean large coal only has in the past tended to secure the most skilful extraction on the part of the men, and it is doubtful whether in those seams where this practice exists, changing to a through coal basis will result in any increased yield.

In one case where it was proposed to change from the large coal to the through coal basis, and the matter was carefully considered, the following conclusion was come to, and consequently the proposal was abandoned :—

| Percentages of output. | Present. | | Proposed. | |
|---|---|---|---|---|
| | Large Coal Basis. | | Through Coal Basis. | |
| | Filling and paying for Large Clean Coal as normally practised. | | Filling and paying for Through Coal. | |
| | Per Cent. | Per Cent. | Per Cent. | Per Cent. |
| Large Clean Coal . . | $67\frac{1}{2}$ | | $59\frac{1}{2}$ | |
| Rubbish in Large . . | $\frac{1}{2}$ | 68 | $\frac{1}{2}$ | 60 |
| Small Clean Coal . . | 27 | | 32 | |
| Dirt in Small . . . | 5 [1] | 32 | 8 [2] | 40 |
| | 100 | 100 | 100 | 100 |
| *Result.* | | | | |
| Large Coal (Clean) . . | $67\frac{1}{2}$ | | $59\frac{1}{2}$ | |
| Small Coal (Clean) . . | 27 | | 32 | |
| Dirt and Rubbish . . | $5\frac{1}{2}$ | | $8\frac{1}{2}$ | |
| | 100 | | 100 | |

[1] Viz., $15\frac{1}{2}$ per cent. of dirt in the small coal sent to the surface.
[2] Viz., 20 per cent. of dirt in the small coal sent to the surface.

That the South Wales coal trade appreciates the value of small coal, and has not been neglgent in providing a commercial outlet for it, is evidenced by the fact that South Wales is much the largest patent fuel (briquette) making district in the country. No other district approaches it, as it produces 94 per cent. of the total make of the country.

*The Relation between Wages and Output.*—The diagram, Plate II, refers to a group of South Wales collieries, and illustrates in detail the relation between the production per person employed per pit working day and the earnings per person employed, also per pit working day, for the past six years—plotted weekly—and averaged each six months.

It will be seen that each rise in earnings is accompanied by a reduced production. Flat rate increases of wages, such as the two war wages and the Sankey wage, have naturally a greater effect on production than percentage increases on Standards. The last advance (20 per cent. on earnings less war wage and Sankey, with flat rate minimums depending on age), being a combination of the two payment systems, may be expected to have an intermediate effect.

If the figures are averaged for the operating periods of each change of wages, the results are more striking, and are as below :—

| | | Earnings per person employed per pit day. | | Production per person employed per pit day. |
|---|---|---|---|---|
| | | *s.* | *d.* | Tons. |
| 1 | No. 1 Pay 1915 to No. 22 Pay 1916. Prior to 15 per cent. advance . . | 7 | 1·30 | 0·768 |
| 2 | No. 23 Pay 1916 to No. 37 Pay 1917. Period of 15 per cent. advance . | 8 | 11·40 | 0·758 |
| 3 | No. 38 Pay 1917 to No. 26 Pay 1918. 1st War Wage addition . . . | 10 | 8·79 | 0·742 |
| 4 | No. 27 Pay 1918 to No. 1 Pay 1919. 2nd War Wage addition . . . | 11 | 11·03 | 0·718 |
| 5 | No. 2 Pay 1919 to No. 29 Pay 1919. Sankey Wage addition . . . | 13 | 7·84 | 0·677 |
| 6 | No. 30 Pay 1919 to No. 17 Pay 1920. Hours reduced 8 to 7 and piecework rates increased by 14·2 per cent. . | 14 | 3·15 | 0·561 |
| 7 | No. 18 Pay 1920. Additional 20 per cent. on earnings . | | | |

The figures include the effect of absenteeism, as ‘pit working days’ are used, not ‘men-shifts actually worked.’

Similar figures for the whole coal-field are not at the writer's disposal, but there is every evidence that the effect is common to all.

The reason for it may be summed up in the platitude that ‘Man works to live,’ and the average miner is only human.

*The Export Trade.*—As already noted, the special nature of the coal produced and the position of the coal-field has led to South Wales becoming the chief coal-exporting district in the country.

The arrangements at the collieries, railways, and docks have been made primarily with export in view, and their equipment is unfavourable, and to some extent useless, for inland trade.

The present reduction on exports is already prejudicially affecting the trade of the district, and if it continues must lead to a transfer of labour, particularly from the docks to other spheres.

## The Discussion.

Mr. H. W. Halbaum.

Opening the discussion on Mr. Bramwell's paper, Mr. H. W. HALBAUM said the importance and significance of the facts brought out in the paper received emphasis from a report which appeared in that day's newspapers—that a Swansea coal exporter had just bought 35 million tons of American coal for the French and Italian markets. These markets in the normal conditions before the war were supplied with Welsh coal, and 35 million tons represented three-quarters of last year's total output from the South Wales coal-field.

Mr. J. Fox Tallis.

Mr. J. FOX TALLIS said he should like to congratulate the author upon the very valuable statistics he had given them. The most serious aspect of the whole position as disclosed

PLATE I.

UTH WALES COAL-FIELD.'

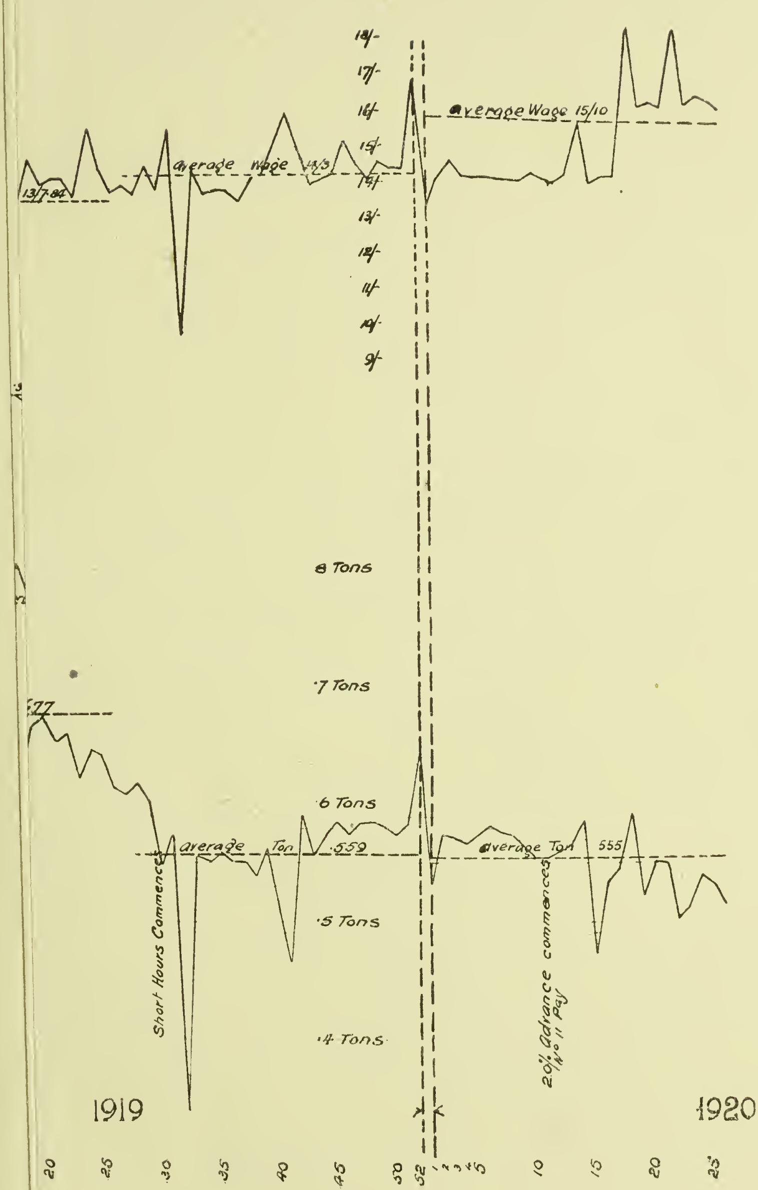


PLATE I.

Illustrating MR. HUGH BRAMWELL'S Paper, 'THE ECONOMICS OF THE SOUTH WALES COAL-FIELD.'
*Proceedings*, Vol. XXXVI. No. 2.

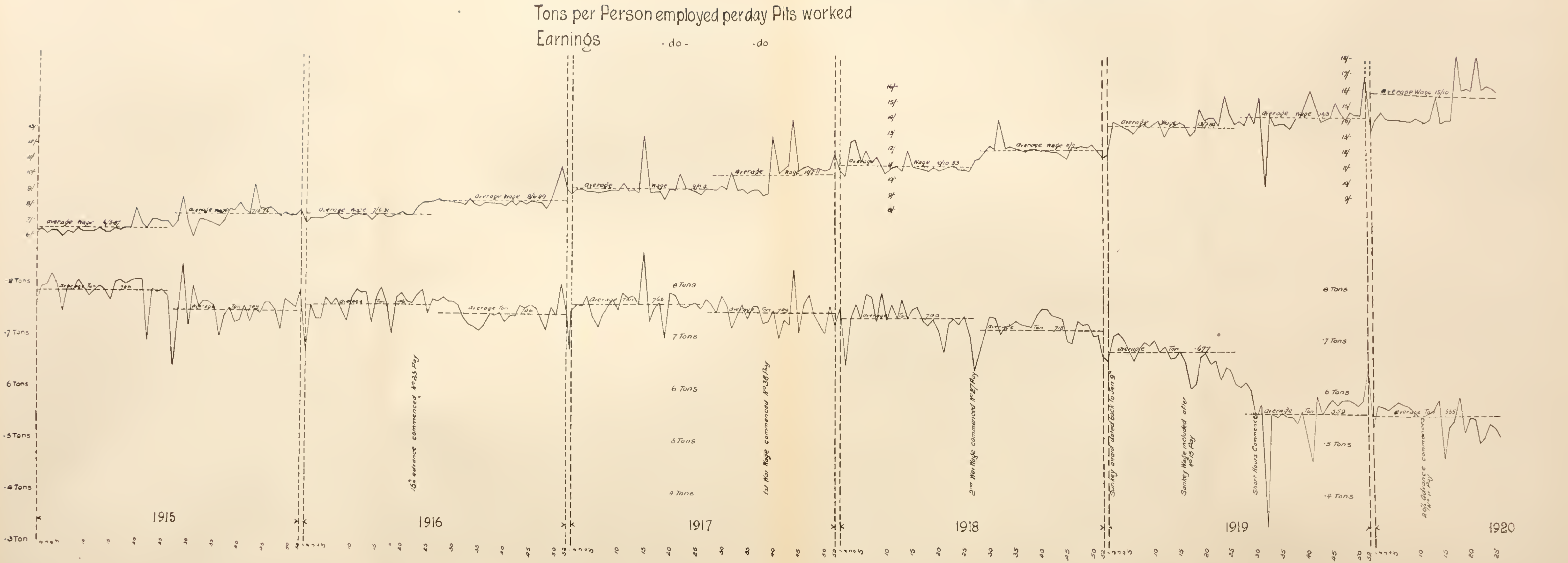
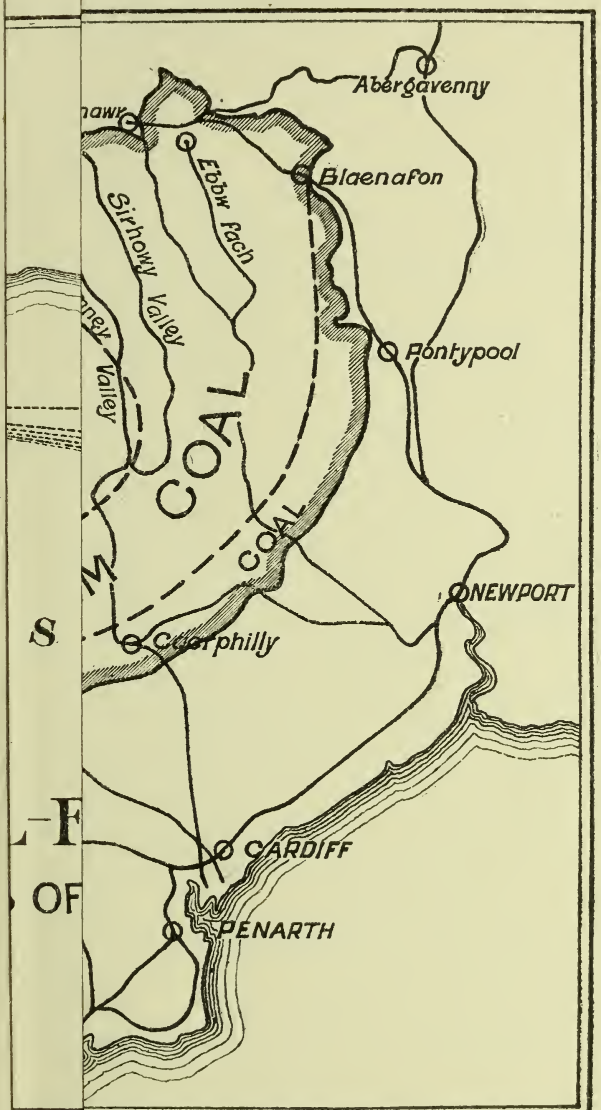
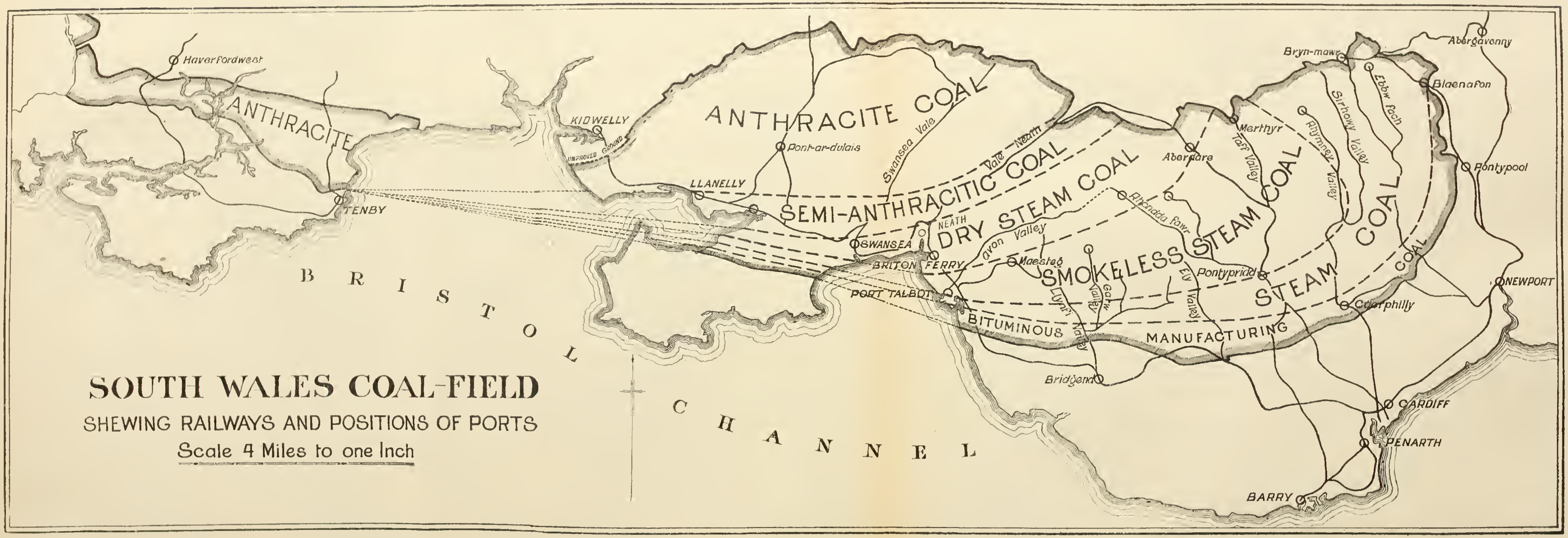


PLATE II.

AL-FIELD.'



Illustrating Mr. Hugh Bramwell's Paper, 'The Economics of the South Wales Coal-field.'
*Proceedings*, Vol. XXXVI. No. 2.




# SOUTH WALES COAL-FIELD

SHEWING RAILWAYS AND POSITIONS OF PORTS

Scale 4 Miles to one Inch

in the paper had reference to the reduction of our coal export, which was nearly killing the trade of South Wales, and not only doing damage to colliery owners and the country generally but was more particularly injuring the workmen themselves. He was interested by the figures relating to losses in 'working through,' leaving coal underground. He endorsed the figures of Mr. Bramwell, which were as nearly accurate as was practicable; but he was inclined to think there was more coal wasted underground by what he might term improper working than there ought to be. By having their faces all laid throughout long-face, continuous faces and all going on together, they had a very much better chance of clearing out the whole of the coal than by the adoption of a different method. He was sorry to say that those in charge of some collieries were always trying to 'strike loose' from one place to another; always driving holes at one little district after another. It was in the large number of small districts where the great waste of working in South Wales occurred, and was much more serious than the waste of small coal left underground. In his experience of working on the longwall system he had produced over 1500 tons of coal per acre per foot thick, which represented the whole of the coal that was in the ground; rather more, perhaps, because there was a certain quantity of rubbish filled out as well, say from 5 per cent. to 15 per cent., which brought down the figures. At these collieries the men were paid for small coal. He did not think they could get a better result than that. He had been impressed with the statistics furnished by Mr. Bramwell of the simultaneous fall of output per man with the rise of wages. The value and significance of those figures were enhanced by the fact that they dealt with continuing periods, in which working conditions remained unchanged. That higher wages should synchronise with falling output per man was a fact which **Mr. J. Fox Tallis.**

**Mr. J. Fox Tallis.**

could not be too widely circulated throughout the coal-field and among our workers generally. (Applause.)

**Mr. John Roberts.**

Mr. John Roberts (Abertridwr) said the question of the waste of small coal formed an interesting and important part of the whole subject so ably dealt with by Mr. Bramwell. He (the speaker) had known collieries where Mr. Bramwell's maximum figure of loss regularly obtained. At one colliery particularly the men were served with boxes for loading the coal which were fitted with screens, or bars about 1 inch or $1\frac{1}{2}$ inches apart, the object being to fill only cobbles and nuts, and allowing the rest to go to waste. He did not quite agree with Mr. Bramwell that small coal mixed with small dirt served a useful purpose in stowing. It certainly served a purpose but he would not call it a useful purpose. Shale would serve a much more useful purpose in supporting the roof. He believed the time would come when the whole of the coal of a mine, or as much as possible, would be loaded separately—the rashings, shale, and small coals, and sent to the surface and washed, and the debris from the washery returned free from coal and used for stowing the gob, either by hydraulic means or in other ways. The sooner this came about the better. Mr. Bramwell stated that a large percentage of the patent fuel made in this country was manufactured in South Wales. That was true, but not nearly as much patent fuel was made in South Wales—or in the country, for that matter—that there ought to be. He noted that a few companies had been started for the purpose of washing shale nuts for the preparation of briquettes, and doubtless they would very soon find many more patent fuel companies operating in South Wales, so as to utilise all the small coal possible.

**Professor W. A. Bone, F.R.S.**

Professor W. A. Bone, F.R.S., chairman of the Fuel Economy Committee, said on behalf of his colleagues and

Professor W. A. Bone, F.R.S.

himself he desired, first of all, to thank the Institute for the arrangements it had made for this meeting, and also for the help and encouragement it had given the Fuel Economy Committee since its inception. He recalled with pleasure and gratitude the fact that the South Wales Institute of Engineers gave the work of the Committee a good send-off at a largely attended meeting held in that hall in 1916, and which he had the privilege of addressing on the subject of fuel economy. One of the results of that meeting, and of the campaign of which it was a part, was the appointment of the Fuel Research Board, whose work was now actively progressing. If their campaign had done nothing more than awake the conscience of the country to the need of fuel research it would not have been in vain. And now, on the occasion of the British Association itself visiting Cardiff, the Council of the South Wales Institute of Engineers had been good enough to organise the present joint meeting, and Mr. Hugh Bramwell had prepared a most valuable and informing paper upon the economics of the coal-field. At the first opportunity the Committee would examine in detail Mr. Bramwell's figures, and would doubtless wish to have the benefit of that gentleman's personal assistance; for they hoped to issue, if possible, next year a report upon the position of the coal export trade of this country. He should like at this meeting to emphasise the importance of fixing public attention upon this vital question of the coal export trade. As they all knew, the country was about to pass through a very serious crisis, which would affect, not only the coal trade, but also the entire fabric of national industry. He did not think he was mis-stating the situation when he said that public opinion was badly and insufficiently informed as to the real facts, and that the state of the public mind was one of bewilderment. Unfortunately, nowadays nobody believed a Government department. (Laughter.)

**Professor W. A. Bone, F.R.S.**

That was a great misfortune. The Fuel Economy Committee had endeavoured to sift the information and to get at the true facts of the situation, but unfortunately its reports did not command that degree of public attention which the great importance of the subject merited. And while the newspapers devoted liberal space to sport and cinema shows, etc., they were lucky if they got more than two or three lines on questions such as that of the coal export trade of the country and the paramount necessity of economising in fuel. A previous speaker had called attention to a report that a countryman of their own had purchased 35 million tons of American coal for export to France and Italy. That statement did not surprise him, except as to the magnitude of the transaction. It should never be forgotten that the basic factor in the economic existence and progress of Great Britain was the necessity of our importing nearly all the raw materials needed for our industries, nearly all the food required to feed the population. Thus, for example, we had to import, in 1913, half of the iron ore smelted in our furnaces, the whole of our cotton, practically the whole of our copper ; 95 per cent. of the zinc ; 90 per cent. of lead, and 80 per cent. of all the wood and timber we used in British industrial establishments. In addition in 1913 we imported £257,000,000 worth of food, drink, and tobacco. The important question arose as to how we were to pay for all these things ; for if we did not get them our big industries would soon have to shut down. An important item in enabling us to pay for these imported articles was the value of the coal we exported. In 1913 we exported 97½ million tons of coal f.o.b., worth 52 million pounds sterling. In addition, the ships employed in that trade earned freights ; and these sources of income from visible and invisible exports enabled us to pay for considerably more than 100 million pounds' worth of raw material. If by the foolishness of any

party we strangled the export trade, we would inevitably shut down the chief industrial establishments of the country. Another highly important reason for fostering the export trade was that, since the war, instead of the country being in the front rank of the creditor nations we had become, if not actually a debtor nation, very much less of a creditor nation than we were before 1914 ; and this made a very great difference from an economic standpoint. Now, with regard to the deal in American coal previously referred to, his Committee were furnished, through the courtesy of the United States Department of Labour, with details as to the movement of wholesale coal-prices in that country. Now, the maximum price of Pocahontas steam coal f.o.b. at Norfolk in 1917 was 29*s.* per ton ; after that period there was a fall to 16*s.* 3*d.* per ton ; last year it was 20*s.* per ton ; and now it was about 24*s.* per ton. Let them compare the cost of production of steam coals in British coal-fields with the f.o.b. wholesale prices of American coal, and they would see that American steam coals had a great pull in selling rates, while they were not far short of being as good in quality as the best Welsh steam coals. **Professor W. A. Bone, F.R.S.**

The PRESIDENT said the paper could not be fully discussed that afternoon, and its consideration would be resumed at the next meeting of the Institute. With regard to the purely mining portion of the paper—and for the present leaving the figures alone—Mr. Fox Tallis had rightly pointed out that in past years the coal faces in South Wales, especially the longwall faces, were not by any means arranged in such a way that the best coal could be won, nor the proper quantity. The faces were often serrated like a rough saw, but an improvement in this respect was gradually introduced ; and it was to be hoped that very soon they would have the faces as level and straight as in many other districts. They could, however, never have them as straight as in the Yorkshire mines **The President.**

The President. and in some parts of the Lancashire coal-field, where the physical conditions were very different from those prevailing in South Wales. With regard to pressure, or 'squeeze,' Mr. Bramwell had very rightly referred to this as a very important point. Most of the best steam coals in South Wales were from 150 to 200 yards of each other, and when one seam was worked there was pressure right through to the bottom. The shales being soft they constantly got tremendous squeezes and crushes; in fact, the whole ground was alive from the seam right up to the seam that had been probably worked before.

Mr. J. Henry Davies, F.G.S. Mr. J. Henry Davies, F.G.S., said as a mining lecturer he came in contact with a large number of young men, and he considered that the reduced output had something to do with the psychology of the mining people. It was due to a change in the outlook of the young men, as compared with the older generation. The young men were not prepared to work as hard as their forefathers had done, but were insisting upon having more education, more recreation, more facilities for travelling, and, in fact, they wanted a better and a fuller life. These could not be obtained if they had to work hard underground for six hours a day; and it was not easy to study. He had noticed that those attending evening classes after coming out of the mine were heavy and sleepy. This never occurred in a day-class. All agreed that the output of coal was a subject of paramount importance; but he was of opinion, from the knowledge he had, that the young miner would insist in the near future upon a six-hours' day and a five-days' week. To increase the output and save large quantities of coal they must look forward to the general introduction of efficient machinery, and to there being a greater number of large collieries and fewer small collieries. The carrying out of the Coal Mines Act, 1911, had partly reduced the output per man working at collieries, because more men were

required to look after the safety of the mine. The number of refuge holes had been more than doubled, and men were required to make them, thus reducing the output of coal per man of those engaged at the colliery. He had visited the best collieries in Great Britain and on the Continent, and some of the large collieries in South Wales would bear favourable comparison with any in Europe. An improved lighting of mines by the introduction of a greater number of lamps at the coal face, and lamps of a higher candle power, would have a tendency to increase the output. By the application of psychology to coal mining and by carrying out work in optimal weight lifted, and the introduction of rest pauses, the elimination of needless movements and periods of slackening there would be an improvement in the quality and quantity of work done. **Mr. J. Henry Davies, F.G.S.**

Mr. Daniel Davies writes: Mr. Bramwell, in his weighty and unbiased exposition of the South Wales coal industry, has shown the unsatisfactory state of affairs at the present time. **Mr. Daniel Davies.**

An increase in the quantity of coal for export is of little use unless there is found a market for the same.

Assuming, however, that if an increased output can be secured its disposal in foreign parts is assured, it is well to consider what may be the root causes for the reduction of output and, if possible, find a means of getting out of a position which is far from reassuring.

It seems almost natural—assuming no change of working methods, e.g. introduction of machinery, etc.—for reduced output to follow an increase of wages. In a community of workers there are probably many who, finding that they can secure the same total wages as hitherto, with less exertion, are content to leave it at that; or, working at the same rate as formerly, the question of disposal of the surplus wages may create a desire for an occasional and extra day off work.

Mr. Daniel Davies.

The above class would probably more than set off the efforts of the more thrifty, who believe in 'making hay while the sun shines.'

The Minimum Wage Act and ungenerous price lists are factors which operate to reduce output. Taking first of all the usual practice of 'going slow' in any seam during negotiations for a price list—which appears to be legitimate tactics, each side seeking to secure the best terms possible—who can estimate the loss of output due to this cause? And when, finally, after much bickering and strife extending for months and sometimes years over a difference of a few pence per ton between both sides, a price list is agreed upon, it offers no great inducement to the worker to exert himself. He is already covered by the Minimum Wage Act, and there is frequently an insufficient incentive in the price list to induce him to give of his very best. Setting aside the 'go slow whatever happens' class of miner, the writer believes that the great majority are eager and anxious to put forth their best efforts, provided it is made worth their while. It is the exception to find more than six hours of actual work done by the miner at the present day, and this is not too lengthy a period to work at high pressure. There is the additional fact that a reduced period of work means greater leisure. In other words, a reduced period for earning means an increased period for spending; and consequently the man requires more money to spend. Herein lies one incentive to the miner to work assiduously during the short period he is underground, and he will do so if there is an inducement to forgo the minimum wage. Let it be supposed that a price list is in vogue, where the man, by working as hard as he feels capable of doing, earns very little if any above the minimum to which he is entitled by law. By taking matters easily and working only half as hard, he may still be paid the minimum without demur. What will be his choice? Human

Mr. Daniel Davies.

nature decrees that it shall be the minimum wage, and, incidentally, the minimum amount of labour necessary to secure that wage. On the other hand, suppose the tonnage price is such that the man, if so inclined, is easily capable of overtopping the minimum by anything from 50 to 100 per cent. In such case he will forget the existence of a Minimum Wage Act.

There are other factors conducive to loss of output; e.g. if the miner, through lack of clearance or shortage of material, finds that his earning power is adversely affected, he is apt to take matters still easier and accept the minimum wage.

Where abnormality exists in the seam, the pernicious habit of taking into account a man's tonnage and paying him an allowance frequently in inverse ratio to the same is responsible for a falling off on the part of many a capable and willing worker. It is the official who bargains *ahead* for the week's tonnage who usually gets the coal out.

It is not proposed to discuss here the causes for lack of clearance; these are well known to mining men.

It has been stated that 'the young men of to-day do not propose to work so hard nor as many hours as their forefathers.' The grave feature is that there appears to be no finality of opinion as to the maximum working period of the future. In the Press some time back a local miner's agent was reported to have delivered himself thus at a gathering of miners: 'When we have secured, and settled down to, a six-hours' shift, we will agitate for four.' A rather disconcerting outlook, in view of the old law that an equivalent of labour is necessary for bacon, boots, and cash.

The writer does not think that Mines Act legislation, because of its greater provisions for safety, is necessarily responsible for a reduction of output per man employed. If that were so, one might expect that the mines of the United

Mr. Daniel Davies.

States, where a very elaborate campaign by the Mines Bureau on 'Safety first' principles has been conducted for years, would show a decided decline in output. As is well known, the contrary is the fact.

The following is offered as a summary of the points which, in the writer's opinion, would make for increased production:

(*a*) The provision of abundant clearance and adequate supplies of material—e.g. timber, rails, sleepers, so as to reduce enforced idleness on the part of the coal hewer.

(*b*) Employ the miner as much as possible in *coal-getting only*, by introducing mechanical appliances to relieve him of work which is not directly productive—e.g. the transport of the coal for some distance to the trams; the handling of trams.

(*c*) Discourage delays on the part of the men in getting to their work, and also the getting away from their work earlier than they should do. Under this head it might be well to consider the question of mechanical transport of the men between the pit and the faces.

(*d*) A reasonably generous tonnage rate to counteract the minimum wage evil. This might entail radical revision, and possible scrapping, of many existing price lists.

The discussion was adjourned.

# CERTAIN CHEMICAL ASPECTS OF THE SOUTH WALES COALS AND COAL-FIELDS.

By S. Roy Illingworth, M.Sc. (Lond.), A.R.C.S., F.I.C.

# CERTAIN CHEMICAL ASPECTS OF THE SOUTH WALES COALS AND COAL-FIELDS.

By S. Roy Illingworth, M.Sc. (Lond.), A.R.C.S., F.I.C.

The South Wales coal-field lies in a basin 920 square miles in area, which approximates in shape to an irregular ellipse; the major axis E. to W. has a length of about 50 miles, whilst the minor axis N. to S. is some 18 miles long. The coal-bearing area extends under Carmarthen Bay and continues as a narrow strip through Pembrokeshire to the sea at St. Bride's Bay. The coal-bearing measures are divided into three zones:

The Upper Measures or Llantwits,
The Pennant Grits or Middle Series,
The Shale or Lower-Coal Series.

The most valuable portion of the measures is contained in the last-named series, which extend from the Farewell Rock up to the No. 2 Rhondda seam. The Pennants extend from the No. 2 Rhondda to the No. 3 Llantwit, and above these occur the Llantwit series, which in the main comprise two outliers in the east in the Blackwood Basin and at Caerphilly.

Dr. Gibson estimates that seams of one foot or over and within 4000 feet of the surface have an aggregate thickness of 28 feet in Pembrokeshire, 47 to 83 feet in Carmarthen, 70 to 124 feet in Glamorganshire, and 38 to 48 feet in Monmouthshire.

These seams contain 31 per cent. of bituminous coal, 47 per cent. of steam coal, and 22 per cent. of anthracite.

*The Classification of the South Wales Coals* has been investigated by C. A. Seyler,* who, from the investigation of a large number of coals, has developed a classification of coal that not only differentiates the salient types of coal in this coal-field, but is of great value in determining the nature of a coal, whatever be its source, from a consideration of its ultimate composition. Seyler points out that the percentage of carbon in a coal (calculated on the ash free and dry coal) determines the species or type of coal, and lays down definite limits for the species of coal that he recognises. These species he terms anthracitic, carbonaceous, bituminous, lignitous. He shows that the volatile matter in a coal varies with the percentage of hydrogen, a direct proportionality does not exist, but excepting the anthracites, of two coals on the same carbon plane, that one which contains the greater amount of hydrogen will have the greater volatile figure, and in general a higher caking index. The amount of hydrogen in a coal determines the genus of the coal.

Seyler regards a certain percentage of hydrogen as characteristic of each species of coal, and coals which contain this amount he connotes as the *ortho* coals of the species. The coals of a species which contain a greater percentage of hydrogen than the normal he denotes by the prefix *per*, and points out that the greater amount of hydrogen causes a coal to approximate in characteristics to that species of lower carbon content, thus a per carbonaceous coal resembles in properties a bituminous coal, i.e. although such a coal viewed from its carbon content should be, say, a free burning steam coal, the enhanced amount

* *The Chemical Classification of Coal*, by C. A. Seyler. Vide *Proc.*, vol. 21, No. 8, and vol. 22, No. 3.

of hydrogen causes it to become a coking coal, which will yield hydrocarbon by-products. Those coals of a particular species which contain a lower percentage of hydrogen than the normal (ortho) species Seyler denotes by the prefix *sub*; in general the sub-hydrous coals resemble that species of coal of next higher carbon content. The consideration of the hydrogen content of coals might be put in the general statement that an increase of hydrogen gives rise to coking and cognate properties, or an increase in the normal ration of hydrogen for any species 'fattens' a coal, a decrease from the normal causes a coal to 'dry.' On any carbon plane, coals of all known variety might occur, according to the hydrogen content; in fact, Seyler states: 'The hydrogen thus seems to be more important than the carbon in determining the kind of coal.' Seyler divides the bituminous coals into three species, denoting each by the prefix *ortho*, *meta*, and *para*, which he uses in the sense that the meta coals contain less oxygen (or more carbon) than the ortho bituminous coals, the para bituminous coals contain more oxygen (or less carbon) than the ortho coals. The meta bituminous coals are short flame coking coals, to which class belong that type of coking coals peculiar to South Wales, namely, coals of a comparatively speaking low volatile which give rise to very dense hard cokes. The other bituminous coals are the normal coking coals, typified by those of Durham and certain seams in Yorkshire. The para bituminous coals are long flaming coals, chiefly of the upper measure in this coal-field, and utilised for gas-making purposes. Diagram No. 1 embodies Seyler's classification, but I have incorporated in it the commercial usages of the various types of coal he defines in his memoir. South Wales is especially famous for its steam coals and anthracites. Seyler differentiates six different classes of steam coal: semi-anthracite, sub-carbonaceous, carbonaceous, semi-bituminous, sub-bituminous, and

pseudo-carbonaceous. The famous Aberdare Admiralty steam coals are of ortho-carbonaceous and semi-bituminous types. The finest qualities belong to the first-named species ; they are possessed of small coking qualities but sufficient for the coal to open out on the bars and prevent the small working through. The dry steam coals all belong to the genus and species of anthracites and carbonaceous coals, consequently they are low

| | Anthracite | Carbonaceous | Bituminous Carbon Plane | | | Lignitous |
|---|---|---|---|---|---|---|
| | | | Meta | Ortho | Para | |
| | C. over 93·3 | 93·3 - 91·2 | 91·2 - 89·0 | 89·0 - 87·0 | 87·0 - 84·0 | 84-80 80-75 |
| Per Bituminous Genus<br>H over about 5·8 %<br>Volatile over 30 % | | | Per Meta Bituminous Species<br>North Country Steam Coals<br>over 5·7<br>30 - 44 | Per Ortho Bituminous Species<br>Bastard Cannels Gas Coals<br>over 5·7<br>over 36 | Per Para Bituminous Species<br>Cannels<br>over 5·8<br>over 40 | Hard Steam Coals |
| Bituminous Genus<br>H about 5·0 - 5·8<br>Volatile 23 - 40% | | Pseudo Bituminous Species<br>5·0 5·8<br>over 23 | Meta Bituminous Species<br>Soft Coking Coals<br>4·9 5·7<br>23 30 | Ortho Bituminous Species<br>Durham Type of Coking Coals<br>Smithy & Gas coals<br>5·0 5·7<br>23 36 | Para Bituminous Species<br>Coking Coals & Best Gas Coals<br>5·0 5·8<br>30 40 | |
| Semi Bituminous Genus<br>H about 4·5 - 5·0<br>Volatile 16 - 24 | | Ortho Semi Bituminous Species<br>Steam Coals (Caking)<br>Higher Index Blended for Coke<br>4·45 5·0<br>14 - 24 | Sub Meta Bituminous Species Index 8 - 17<br>House Coals Continental<br>Coking Coals when Index is High<br>4·5 4·9<br>16 - 23 | Sub Ortho Bituminous Species<br>Coking & Steam<br>4·5 5·0<br>16 - 23 | Sub Para Bituminous Species<br>? 5·0<br>16 - 29 | |
| Carbonaceous Genus<br>H about 4·0 4·5<br>Volatile 10 - 16 | Semi Anthracitic Species<br>Dry (Non Coking) Steam<br>4·0 4·5<br>9 15 | Ortho Carbonaceous Species<br>Welsh Smokeless Steam<br>Slight Caking<br>4·20 4·45<br>10 14 | Pseudo Carbonaceous Species Sub Meta Bituminous<br>Steam Coals<br>3·7 4 5<br>10 - 16 | Sub Ortho Bituminous Pseudo Carbonaceous Species<br>? 4·5<br>? 16 | | |
| Anthracitic Genus<br>H under about 4·0 %<br>Volatile " " 10 % | Ortho Anthracitic Species<br>True Anthracites<br>under 4<br>5 - 9 | Sub Carbonaceous Pseudo Anthracitic<br>Dry Steam (Non Caking)<br>Bastard Anthracites<br>under 4·2<br>under 7·7 | Sub Meta Bituminous Pseudo Anthracitic<br>under 3·7<br>under 10 | | Sub Para Bituminous Pseudo Anthracitic<br>under 4·2<br>under 10 | |

FIG. 1. SEYLER'S CLASSIFICATION OF COALS.

in hydrogen, and possess no coking power. The coals utilised for coke manufacture belong mainly to the meta, some to the ortho bituminous series, but to-day many of them are of the semi-bituminous genus, i.e. sub-meta and sub-ortho bituminous coals. It is interesting to note that the Welsh steam coals are higher in carbon and lower in hydrogen than the coking coals, whilst the North country, Scotch, and Midlands free burning steam coals are in general of higher hydrogen and lower carbon than the coking coals, e.g. the latter are inter-

mediate in nature between the Welsh and other free burning coals of the United Kingdom.

*Distribution.*—The salient feature as regards the distribution of the various types of coal within the South Wales coal-field is the fact that at any particular place in general the passage from the higher to lower seams is concomitant with a decrease in the volatile matter of the coals. The upper seams (Llantwit's) range in volatile from 37 to slightly over 40 per cent., the Pennant Grit seams range from 19 to about 37 per cent., whilst the lower seams vary from 5 to about 20 per cent. volatile. The figures given are very approximate, since another very remarkable feature of any particular seam is the fact that on the eastern borders of the coal-field all the coals tend to be of the bituminous species. As one follows any seam in a westerly direction there is a gradual diminution in volatile matter, a consequent decrease in hydrogen, and an increase in carbon, until finally the coal in the east is of the anthracite species. This feature is reflected in the investigation of samples of the 9 foot seam shortly to be described.

A similar change is evident in passing along any seam from the N.E. to S.W.; the coals increase in volatile matter in this direction; seams which are of a carbonaceous or semi-bituminous nature in the N.E. become highly bituminous along the south crop of the coal-field. Strahan and Pollard in 'The Coals of South Wales' ('Geological Survey Memoir') discuss the ultimate composition in relation to the distribution of the typical coals, and show that the ratio of carbon to hydrogen increases in a definite manner from E. to W. for each seam. The geographical variation of this ratio is shown in Figs. 2 and 3 for the 9-foot seam and for the No. 2 Rhondda, by means of the lines joining places at which the coal of the seam has the same ratio C/H. These lines Strahan terms iso-anthracitic lines.

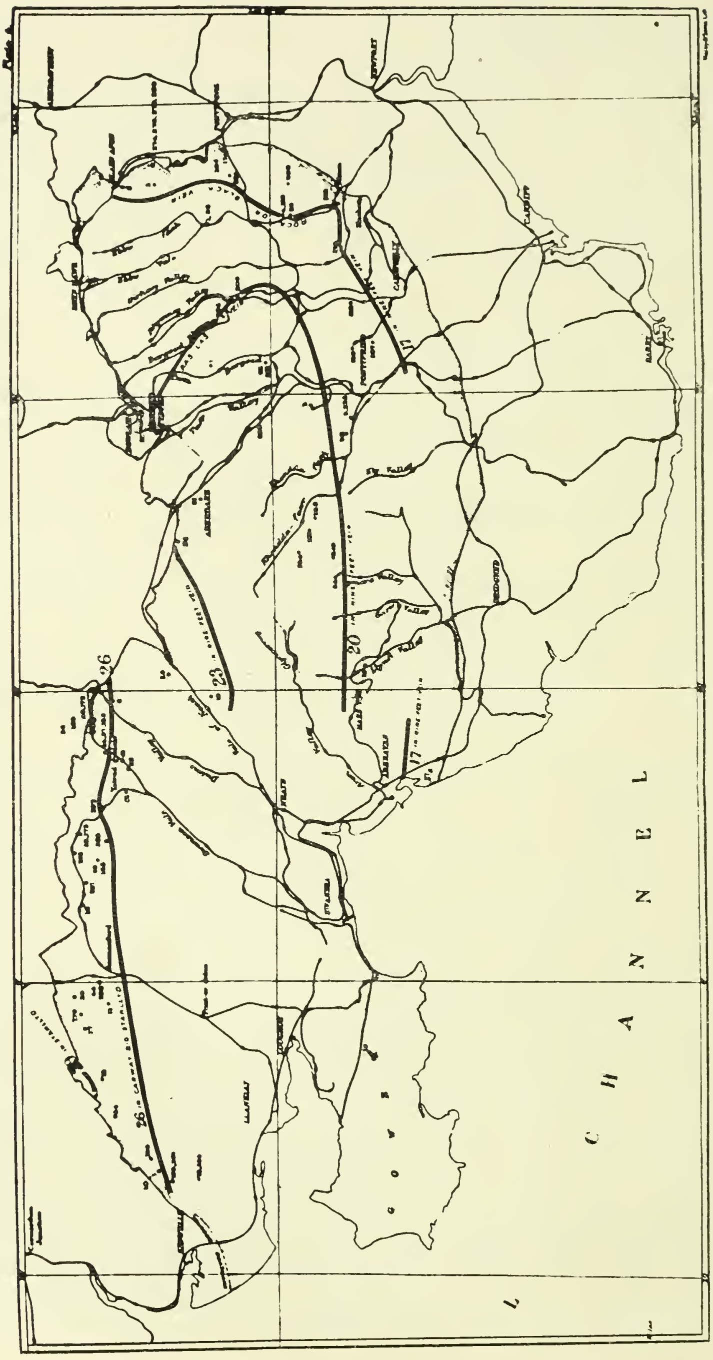


FIG. 2.

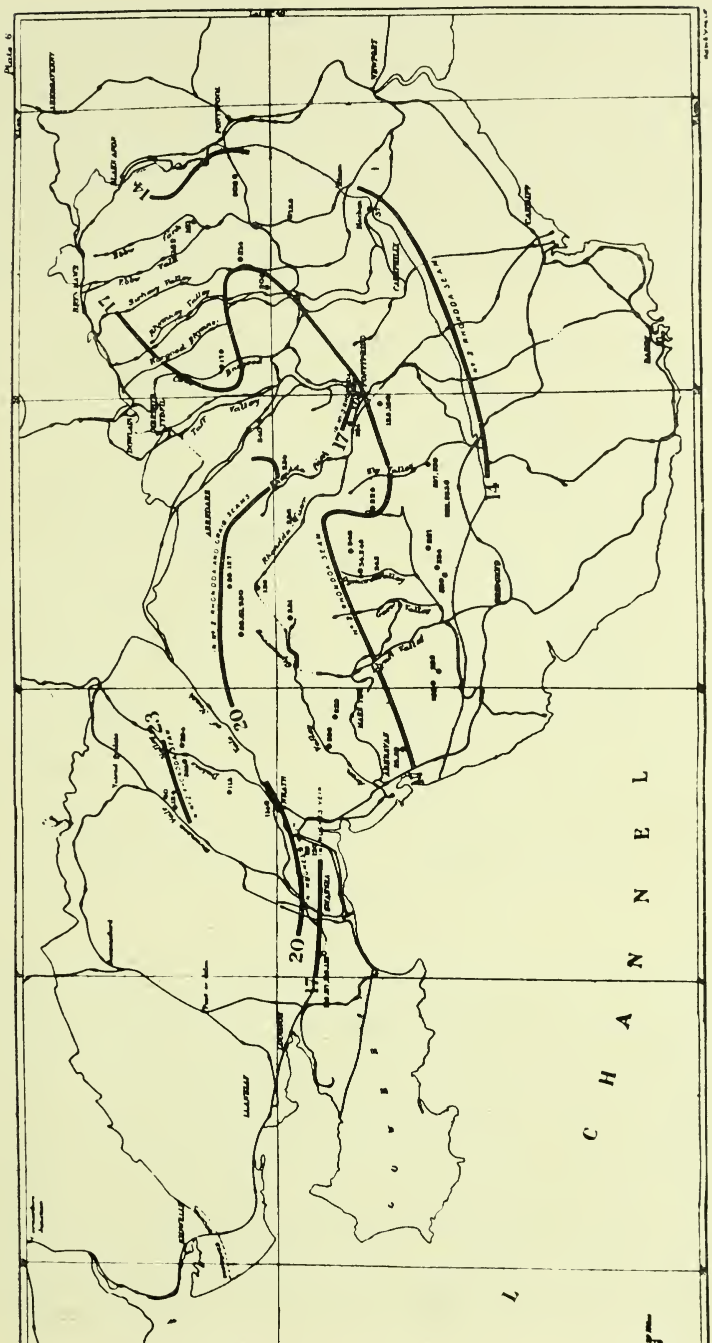



Fig. 3.

During the past two years I have been engaged upon a programme of research at the School of Mines, Treforest. The expenses connected therewith are defrayed by a group of South Wales collieries. The results of the work so far published are contained in three Papers in the 'Proceedings' of this Institute, vol. 35, No. 2, and vol. 36, No. 1. These investigations were concerned with that interesting class of Welsh coals which

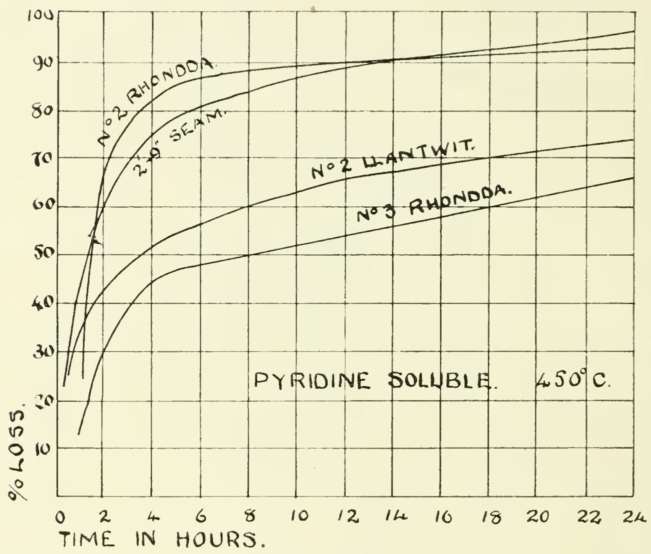



FIG. 4.

give rise to coke of one type or another. It was found that the temperature of coke formation increased with increase in the carbon-hydrogen ratio, and ranged from 380° C. for the gas type of coals to approximately 470–500° C. for the semi-bituminous coals. The ease of decomposition of the pyridine soluble, $\beta$-cellulosic and resinic types of substances was studied at 450° C., and it was shown that the percentage decomposition varied with time. The true coking coals were the more readily decomposed, and they contain a type of $\beta$-cellulosic substance

that appears to be nearly homogeneous in nature. Moreover. this type of substance was readily decomposed; it was very much less stable than the resinic constituents of the coking coals, or than the similar constituent and $\beta$-cellulosic of the gas coals. The results are represented graphically in Figs. 4, 5, 6. It was further shown that the resinic and $\beta$-cellulosic constituents of each coal were of two types as regards their

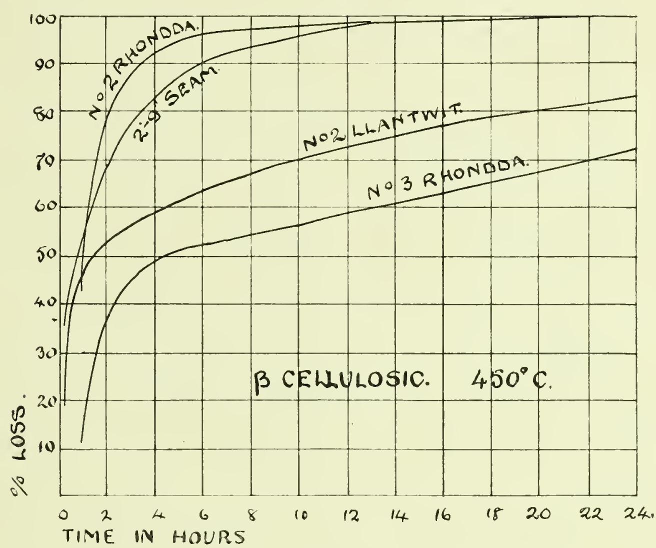



FIG. 5.

thermal stability, and that a round 5 per cent. of resinic substance was necessary in any coal in order to cause that coal to coke. New views on the theory of coking were advanced, but space forbids touching on this matter; the object of mentioning these results will be clear in the sequel to the work now to be described.

Recently I have commenced an investigation of other typical coals of South Wales, the object of which is to attain some insight into the fundamental differences of these coals.

The work is largely correlated with the problems attacked by Seyler and also by Strahan and Pollard. Inasmuch as a knowledge of the fundamental differences of the typical coals will shed light on their classification, and since the coals so far examined are drawn from different places in the 9-foot seam, the information obtained should assist in the elucidation of the gradual change in the nature of the coal in an east

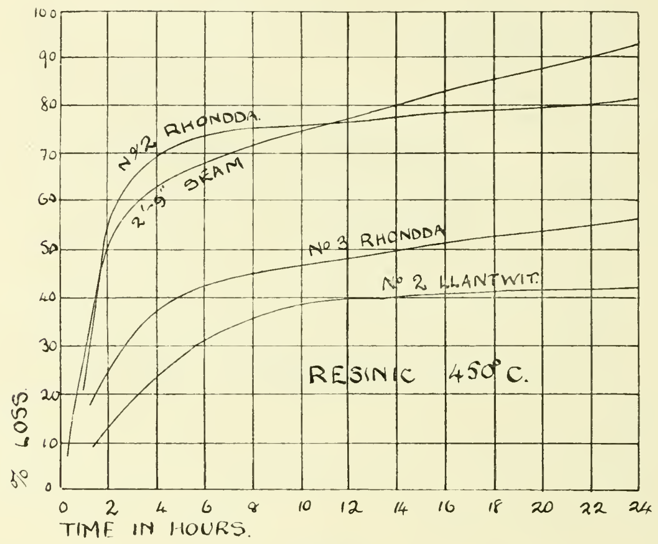



FIG. 6.

to west direction; that is, it should assist toward a solution of the problem of the origin of anthracite. The work is far from complete, but perhaps the following résumé of its progress will be of interest. I have included in the present communication the No. 2 Llantwit, inasmuch as the series detailed is then representative of the typical South Wales coals.

The coals examined gave the following analytical results. The samples experimented upon were mine samples cut from roof to floor of the seam.

Analyses of Coals Investigated.

| | No 2 Llantwit. | Nine-foot Seam. | | | | |
|---|---|---|---|---|---|---|
| | | A. | B. | Y.O. | O. | W.V. |
| Volatile (900°C.) . | 37·06 | 29·50 | 18·55 | 15·60 | 9·39 | 6·40 |
| Fixed carbon . | 57·53 | 65·20 | 73·54 | 76·04 | 82·86 | 90·40 |
| Ash . . . | 5·41 | 5·30 | 7·91 | 8·02 | 7·75 | 3·20 |
| On ash free dry coal. Volatile . | — | 30·60 | 20·15 | 16·94 | 10·72 | 6·61 |
| C. . . . | 82·87 | 88·75 | 89·69 | 90·96 | 92·94 | 93·74 |
| H. . . . | 5·80 | 4·97 | 4·48 | 4·34 | 3·45 | 3·32 |
| O. . . . | 7·76 | 3·36 | 2·24 | 1·87 | 1·93 | 1·28 |
| N. . . . | 1·49 | 1·23 | 1·58 | 1·43 | 0·89 | 0·74 |
| S. . . . | 2·08 | 1·69 | 2·01 | 1·40 | 0·89 | 0·92 |
| Ratio C/H . | 14·29 | 17·82 | 20·00 | 21·00 | 26·95 | 28·20 |
| Calorific value . | 8134 | 8474 | 8570 | — | — | 8433 |
| Sp. gravity . | — | 1·258 | 1·276 | 1·281 | 1·370 | 1·416 |
| Coking index . | 24 | 23 | 16 | 12 | nil | nil |

The No. 2 Llantwit is a gas coal. The samples of the 9 foot seam are arranged left to right in the table in the order that the places from which they are drawn are situated east to west in the seam. Increase in the carbon-hydrogen ratio and of the specific gravity of the coal substance, decrease in the coking index is evident in the coal of the seam from east to west. The A. sample represents a typical South Wales bituminous coal, used as a house coal for coking, also for locomotive use. The B. sample approximates to the average quality of the low volatile Welsh coking coals. The Y.O. coal is typical of the Welsh semi-bituminous steam coals, with slight coking qualities, whilst the O. coal represents a dry steam coal, i.e. it is a bastard anthracite. The W.V. coal represents a true anthracite. The nomenclature to be adopted on Seyler's basis will be evident by comparing the analyses given with the limits set out in Fig. 1; it must be noted that

these analyses are corrected for the mineral carbonate and pyrites in the samples, hence the results for carbon may be slightly lower than the usual determinations.

The method of investigation adopted was similar to that in my previous work ('Proceedings,' vol. 36, pp. 20–86). Twenty-five grams of the dry-washed coal, ground to pass a 20-mesh sieve and be retained on one of 60-mesh, were heated in the retorts in the apparatus shown in Fig. 7. The details

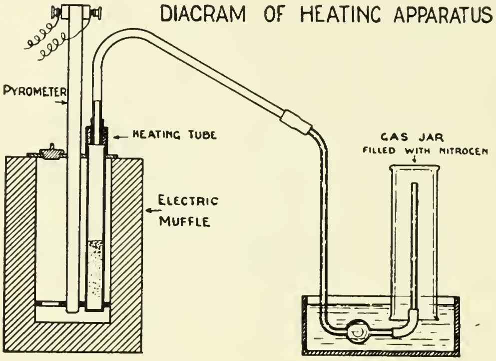



Fig. 7.

of the procedure adopted to obviate oxidation are set out at length in the Paper mentioned above.

The initial temperature adopted was 300° C. The charge was heated at this temperature for two hours, the tube withdrawn, and the contents after cooling were washed with cold carbon tetrachloride, dried in vacuo, and weighed. The residue was returned to the tube, which was heated for another small increment of time (2 hours) at 300° C., cooled, and the residue dealt with as above. The residue was again returned to the tube, heated for another interval of time, and in this manner the whole of the substance volatile at 300° C. was driven off in successive stages. The procedure was continued until the weights of the residues from two successive heatings agreed to within 0·10 per cent., i.e. the curve representing the loss

of weight with time at a particular temperature became horizontal. It should be mentioned that the method was found to give repeat results within the limit of error $\pm 0 \cdot 2$ per cent. When the total amount of substance decomposable at 300° C. had been evolved, the residue was then heated at 350° C. for successive intervals of time, and the volatile matter evolved during each period was determined; again the

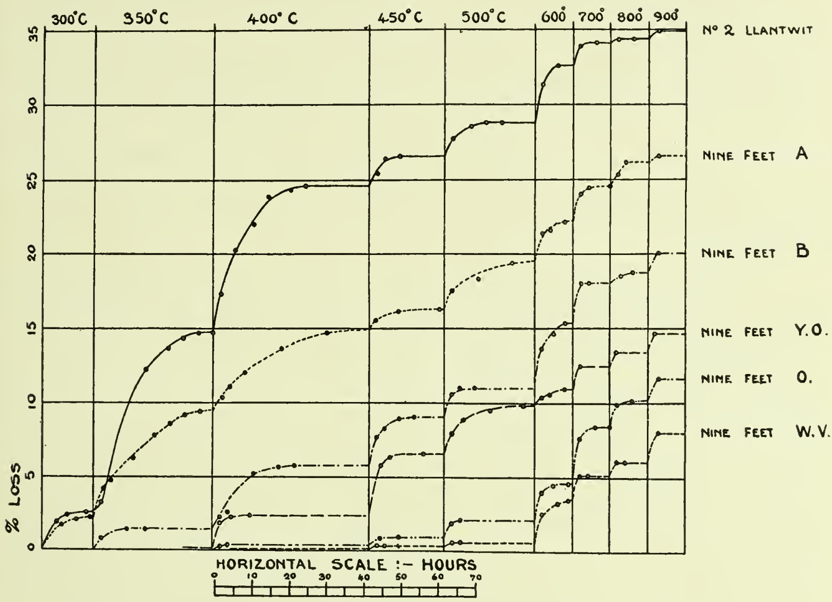



Fig. 8.

operation was carried on until no further decomposition was evident. Proceeding in this manner for successive temperature increments of 50° C. up to 500° C., and then adopting increments of 100° up to 900° C., the whole of the volatile matter of the coal was evolved, and an indication of the stability of the coal substance over the range of temperature 300° C. to 900° C. was obtained.

The results for the coals considered are given graphically in Fig. 8; the ruled ordinates demark the various temperatures.

Insomuch as at a particular temperature the period of heating necessary to decompose the whole of the substance varied with the coal, the spacing of the ordinates is such as to represent the longest period required; in the other coals the curves have been continued horizontally to the next temperature ordinate, consequently the curves for all coals at the same temperature commence at the same place.

The interpretation of these curves must of course take into consideration the facts that the substances undergoing change at any particular temperature are either (*a*) the original (primary) substances present in the coal, (*b*) products (secondary) resulting from the thermal change at a lower temperature of primary substances, or (*c*) a mixture of primary and secondary substances.

Whatever be the nature of the substances it is evident that since a coal must pass through that range of temperature omprised between ordinary atmospheric temperature and the maximum attained in the utilisation of the coal, the curves do constitute a reflex of the behaviour of the various coals either when carbonised or burnt. The difference between these curves and actual conditions is conditioned by the time temperature factor, i.e. the time the coal is exposed to any particular limits of temperature. Since the conditions of experimentation were the same for each coal, the following conclusions are to be drawn from the curves:—

(*a*) The initial temperatures at which active decomposition commences are:

(1) For the No. 2 Llantwit and A. at or below 300° C.
(2) For B. .. above 300° C. but below 350° C.
,, Y.O. .. ,, 350° C. ,, 400° C.
,, O. .. ,, 400° C. ,, 450° C.
,, W.V. in all probability about 500°, since the small loss of weight found to occur at 400° and 450 ° C. may be

due to occluded gases, in which the anthracites as a class are particularly rich.

(*b*) The individual parts of the curves to the right of the

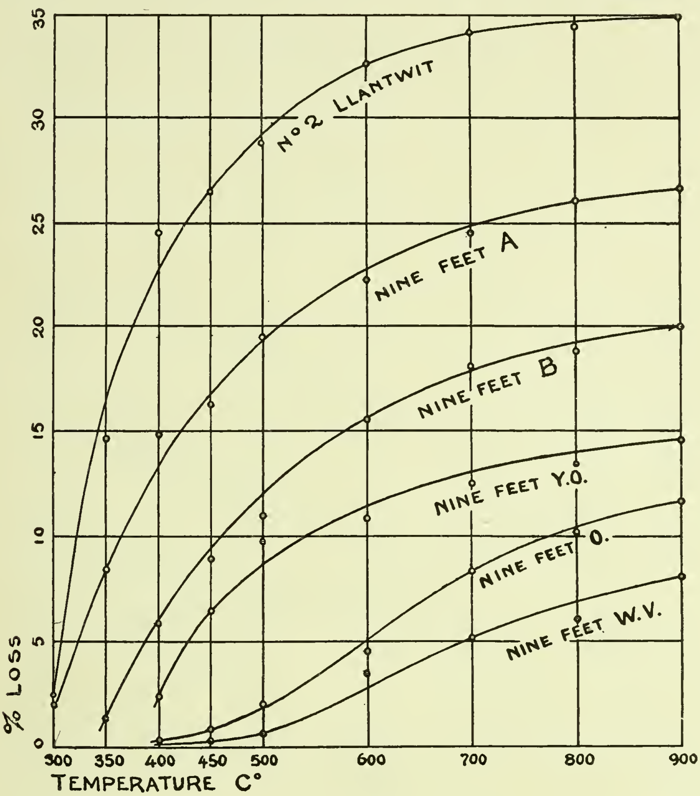



FIG. 9.

500° C. ordinate are of the same general nature, which fact may be taken as due to the similar chemical nature of that portion of the coal substance or products therefrom stable above 500° C. The amount of this portion of the coal substance is practically the same in each coal.

(*c*) That portion of the curves representing the behaviour of the coals below 500° C. reveals marked differences in character, due to the presence in the coals of substances of different stability in varying amounts.

(*d*) The generalisation can be tentatively propounded: 'That it is the behaviour of a coal at temperatures below 500° C. which determines its characteristic properties and economic uses.'

Fig. 9 represents the sum of the maximum volatile matter evolved up to any temperature plotted against the temperature. It will be noted that there is a general tendency to parallelism

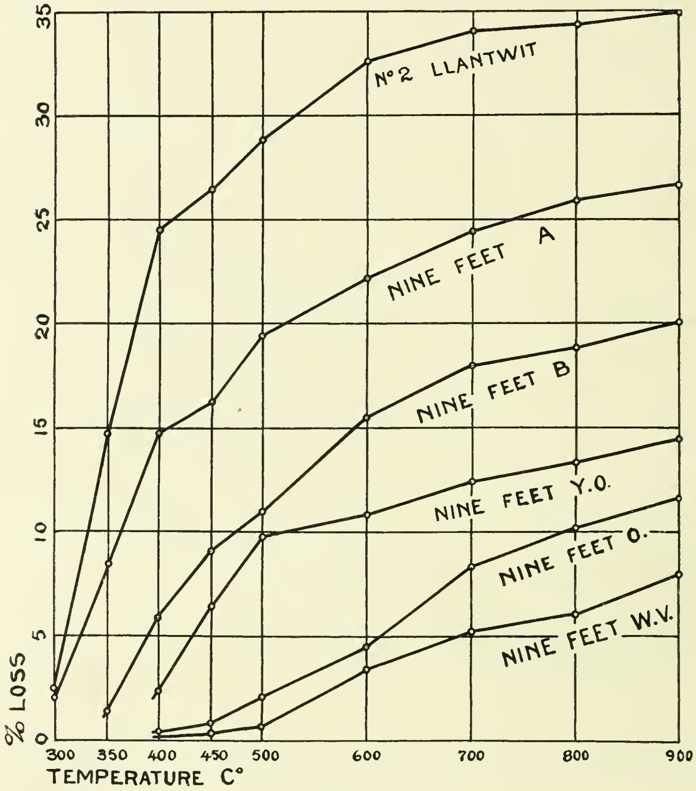



FIG. 10.

of that portion of the curves between the temperatures 500°C. and 900° C. Moreover, the volatile matter evolved over this range varies for the individual coals between the limits 6 and 8 per cent. The reason for the higher volatile figures of the bituminous coals is due to the presence therein of substances unstable below 500° C. In all probability a point of flexure exists on these

curves between the temperatures 500° C. and 700° C., a possibility that is the more evident from the curves in Fig. 10. The smaller rate of increase in the volatile matter evolved with increase of temperature is to be remarked in the three lower coals, all of

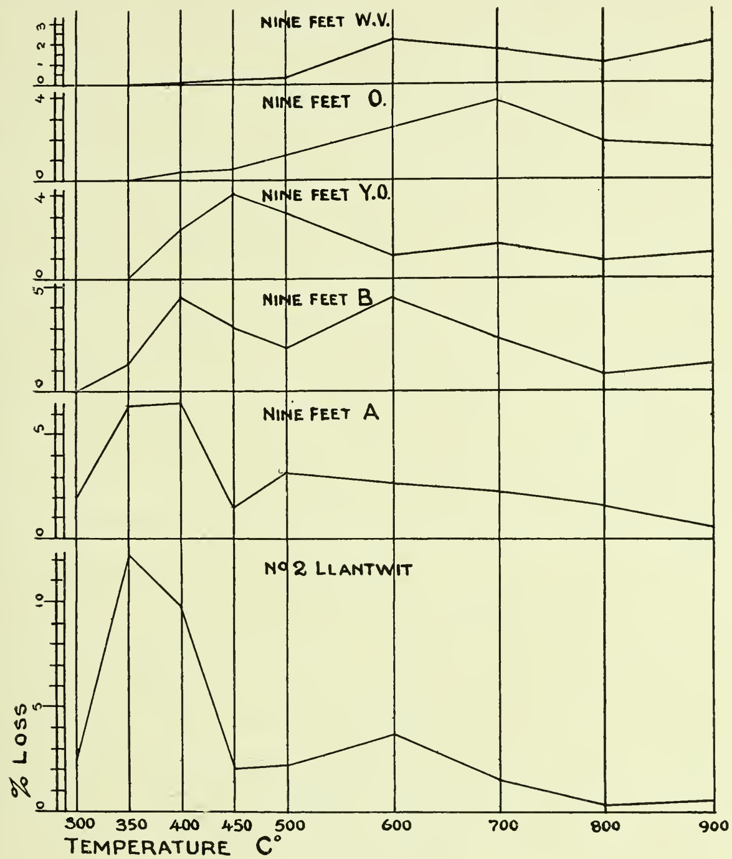



FIG. 11.

which represent practically smokeless coals, a property no doubt due to the fact that the smaller amount of volatile and its more gradual evolution with rise in temperature permits of the amount evolved obtaining the quantity of oxygen requisite for complete combustion, at a temperature well above the ignition point. On the other hand, the bituminous coals fed

on to a vigorous fire evolve volatile matter at a rate too rapid for the draught to supply the oxygen necessary for complete combustion; the same coals fed on to a 'slow fire' evolve volatile matter at a temperature near to the ignition point of the constituent hydrocarbons, and may be below that of some of them. Hence incomplete combustion results.

Fig. 11 represents the successive evolution of volatile matter at successive definite temperatures, i.e. the ordinates of the curves represent the amount of volatile matter evolved at the temperatures given, when the residue from the previous heating operation is heated at that temperature till no further volatile matter is evolved. The curves for the anthracitic coals show only one maximum point, namely, at 600° C. to 700° C. The bituminous coals show a maxima at 350° C. to 400° C., and another at 500° C. to 600° C., whilst although the semi-bituminous coals show a lower maxima, it occurs at 400° C. to 450° C., which indicates that the portion of the coal substance decomposable at the lower temperatures is yet more stable than the similar portion of the bituminous coals; the semi-bituminous coals also reveal the 600° C. to 700° C. point of maximum evolution of volatile. It is interesting to recall the fact that Wheeler ('Trans. Chem. Soc.') regarded 600° C. to 700° C. as the initial decomposition point of a substance in coal which yielded large amounts of hydrogen, a view that was contested by Porter on the grounds that this hydrogen might arise due to the production of secondary products.

To sum up this aspect of the investigation. The temperature of initial active thermal decomposition of the coals considered increases with the increase of the carbon-hydrogen ratio. The amount of successive decomposition at definite temperatures is characterised by maxima at an upper and a lower range of temperature. The upper limits are between 600° C. and 700° C. for each type of coal. The lower temperature range increases

with the increase of the carbon-hydrogen ratio and ceases to be evident in the carbonaceous and anthracitic coals. In a word, it appears that the thermal stability of the coal substance, viewed as a whole, increases with increase in the carbon-hydrogen ratio.

I have shown in a previous paper that the decomposition of the coal substance at temperatures up to 450° C. is largely the decomposition of that portion of the coal soluble in pyridine. The final residues arising at the temperatures considered for the above coals were extracted with pyridine in an atmosphere of nitrogen, and the pyridine extract was subsequently extracted with chloroform. The results obtained agreed to a half per cent. for extraction with pyridine either under pressure at 160° C. or in soxhlets at ordinary pressure, provided that decomposition of the coal substance had taken place to as small an amount as 1 per cent., a behaviour no doubt due to complete depolymerisation of the coal substance. The results are detailed in the following tables:—

Pyridine Soluble. Constituents present in Residues from 100 parts of Coal Substance.

| Nature of Residue. | A. | B. | Y.O. | O. | W.V. |
|---|---|---|---|---|---|
| Final residue at 300° C. | 31·99 | — | 0·91 | trace | nil |
| „ „ 350° C. | 22·43 | 10·46 | 0·62 | „ | „ |
| „ „ 400° C. | 3·16 | 4·00 | 9·24 | „ | „ |
| „ „ 450° C. | nil | nil | nil | nil | „ |

It is interesting to note that the results for the Y.O. point to the fact that a minimum temperature exists for depolymerisation to take place.

These results show—

(*a*) That the carbonaceous and anthracitic coals contain no pyridine soluble constituents.

| Residue. | β-cellulosic in Residue *ex* 100 Coal Substance. | | | Resinic in Residue *ex* 100 Coal Substance. | | |
|---|---|---|---|---|---|---|
| | A. | B. | Y.O. | A. | B. | Y.O. |
| Final at 300° C. . | 17·07 | — | — | 14·92 | — | — |
| ,, ,, 350° C. . | 13·00 | 2·70 | — | 9·43 | 7·76 | — |
| ,, ,, 400° C. . | trace | trace | 2·32 | 3·00 | 3·72 | 6·92 |
| ,, ,, 450° C. . | nil | nil | nil | nil | nil | nil |

(*b*) That in those coals which contain these constituents the thermal stability of such substances increases with increase of the carbon-hydrogen ratio of the coals.

(*c*) The pyridine soluble constituents of the true bituminous coals is of two types, viz. a portion decomposed below 350° C. and a portion stable above that temperature, but mainly decomposed below 400° C. It is the thermal instability of the first portion which differentiates the bituminous coals from the lesser and semi-bituminous type of coal, the pyridine soluble portions of which are stable above 400° C.

(*d*) Taking into account the results of my previous researches on the coking coals, a summary of which will be found in this Institute's 'Proceedings,' Vol. 36, pp. 57–60, the lesser bituminous (sub, ortho and meta bituminous or true coking coals) are differentiated from the para bituminous coals (gas coals) by a smaller content of β-cellulosic type of constituent, and its relative much greater instability compared to its resinic type of substance. The semi-bituminous coals are differentiated from the above by a lesser content of pyridine soluble constituents, and, comparatively speaking, an approach to the absence of β-cellulosic substance.

Taking these results into consideration with the curves previously discussed, it may be stated that properties of the different species of coal are differentiated by the amounts

of pyridine soluble constituents ($\beta$-cellulosic and resinic substances) they contain, the thermal stability of these substances, their amount, their stability relative to one another and to their nature; for I have shown (*loc. cit.*) that the amount of volatile matter evolved at particular temperatures from various constituents of different coals decreases with increase of the carbon-hydrogen ratio of these substances.

At no stage in the heating of the coals in the manner described above was there any production of coke, yet the residues resulting from the A. and No. 2 Llantwit coals at 350° C., likewise the residues from the Y.O. and B. coals at 400° C., gave dense hard cokes when carbonised at 900° C.; but coking properties were destroyed in the first-named coals after 400° C., and after 450° C. in the case of the latter coals. This behaviour is attributed to the slow destruction of the resinic constituents in the above procedure, with the result that the binding skeleton of carbon is not coherent. It shows that the properties of a coal are conditioned by the conditions of usage; that is, by the time-temperature gradient of a charge. Thus a Welsh semi-bituminous coal fed on to a fire in thin layers would tend to coke, whilst if 'banked' on a fire would tend to be quite free burning, and perhaps it would not open up.

It is evident from these results that by a process of 'fractional decomposition' it is scientifically possible to produce from highly bituminous coals any desired type of semi-bituminous, dry steam or anthracitic coal. For example: by elimination of the portion of the A. coal decomposed below 350° C. there results a true dense coking coal, elimination of the resinic and $\beta$-cellulosic substances decomposed below 400° C. should produce a semi-bituminous coal of the Admiralty type, whilst carbonisation at 500° C. will result in a dry steam coal.

The variation of the amounts of hydrogen in a coal constitutes a reflex of the resinic constituents present or an absence of $\beta$-cellulosic substances. Seyler's per-hydrous coals may be termed 'resinic' coals, and, as he shows, such will be more bituminous in nature than the ortho coals of the particular species considered. The sub-hydrous coals are equivalent to 'non-resinic coals,' and such will naturally be of a more carbonaceous nature than the ortho species. Space forbids development of this subject, but evidence is forthcoming that Seyler's classification based on the hydrogen content is on a true scientific basis, reflecting the chief substances determining the characteristic of coal.

Finally, it may be remarked that, concurrent with this chemical investigation of the coals, geological work is being carried out by Professor Knox, and it is hoped that correlation of the results will shed further light on the origin of coal. The work here recorded reveals a graduation in the properties of the coal in the 9 foot seam in an east to west direction; tentatively the view may be put forward that these changes arise from the elimination from the matrix from which the coal is formed of the protein and cognate substances which constitute the resinic portions of the coal. This elimination has taken place due to bacterial agency, either in the original matrix *in situ* or in regional swamps; and subsequently selective deposition of the altered matrix has taken place, the lightest portions being carried farthest, and a gradation in density of the deposited mass has resulted from shore line out to deeper water, due to variations in density of the matrix altered according to the degree of bacterial change. The anthracites appear to be composed of highly comminuted matter, but as yet no satisfactory micro-sections have been made. Maybe the most decayed portions of the matrix are the lighter, due to gases occluded during the change. Maybe they are also the more

'spongy' and thus less resistant to pressure, which, arising from deposition of overlaying sediments, would press the mass into one of greater density; for it must be recalled the anthracites are of the greatest density. Maybe the changes occurred after sedimentation. But these points and the relation of the distribution to physical conditions of sedimentation are yet to be cleared up.

I desire to thank the Members of the Board of the School of Mines for the facilities enabling this work to be done. Again I wish to place on record my indebtedness to Professor Knox for his keen interest in the work and his ever-ready endeavours for its furtherance. To my colleague, Mr. Metcalfe of the Engineering Department, I am beholden for much help—for the preparation of the diagrams and for assistance with the apparatus necessary for the work. I desire to thank Messrs. Foster Jones, Ivor Lane, and H. Gibson for their help in connection with certain parts of the analytical work.

## The Discussion.

The author having outlined the chief points of his paper, aided by the exhibition and explanation of lantern slides,

**The President.** The PRESIDENT said they were all very proud of having a gentleman in their midst who was able to carry on these researches in the admirable way in which Mr. Illingworth was doing. (Applause.)

**Professor Bone.** Professor BONE said he had read the paper and listened to Mr. Illingworth's explanatory observations with the greatest possible interest, and he congratulated that gentleman, and the Institute, as well as the generous supporters of the Treforest School of Mines, upon the accomplishment of so important

Professor Bone.

a piece of work. No words of his were needed to command support for this kind of thing from the hard-headed business men of South Wales; and he wished Mr. Illingworth and his collaborators every success in the further prosecution of their researches. He felt confident that in the author's able hands they would lead to results of economic value. (Hear, hear.) The problems upon which Mr. Illingworth was engaged had a wider interest than even attached to them in South Wales, because he was investigating the fundamental properties of coal; and he (the Professor) was sure it would be the wish of his Committee if the author of the paper would come and join them and take part in their deliberations, because the Committee hoped to formulate a Report or Memorandum by next year dealing with some of the points he was now investigating. If he might be allowed a word or two of friendly criticism as a fellow-investigator of similar problems, there were one or two conclusions arrived at by Mr. Illingworth which to his mind were not quite convincing. They were dealing with a very complex subject, and it was very easy to draw particular conclusions from a given set of results that did not necessarily apply generally to coal as a whole. From a statement made in the paper, Mr. Illingworth apparently held the opinion that the coking properties of coal were dependent chiefly upon the resinic constituents. Three or four years ago he (Professor Bone) thought the same, but he was beginning to think differently. For two years he had been investigating this problem, and he found that he could extract by certain neutral solvents the resinic constituents from coal without impairing very materially the coking properties. He had not published the work yet, and he would like to ask for a suspended judgment on this point. He had no doubt that Mr. Illingworth's facts were quite correct, and perhaps he was getting hold of one part

of the truth only. There was one thing about pyridine of which they should take heed. Mr. Illingworth had used pyridine as a solvent for coal. Its solvent action was discovered by Professor Bedson, whom he saw present at the meeting, and Wheeler had used it largely in his researches. Wheeler had claimed that it removed from the coal substances what were usually termed the resinic and the *beta* cellulosic constituents. He (the speaker) thought that was a rather rash conclusion. He had never been completely convinced by the evidence which Wheeler had adduced. It was one thing to discover new facts, and quite another to interpret them correctly. What was most needed in contemporary scientific work was greater ability to deduce accurately sound conclusions from ascertained facts. Well, now, pyridine had two actions upon coal, i.e. one was an ordinary solvent action and the other was depolymerisation. It was not strictly true to say that *beta* cellulosic compounds were dissolved by the pyridine. It was a dangerous solvent to use if they meant to arrive at scientific conclusions, because of the two actions that took place. He preferred to use more neutral solvents. He put this forward as a caveat in regard to some of the propositions in the paper. He thought Mr. Illingworth's conclusion that differences in coals were chiefly differences when subject to a temperature below 500° C. was perfectly sound, but they must not look simply at resinic and cellulosic constituents, because there were other constituents. However, he should like to have an opportunity of discussing these points over the Committee table, and he gave Mr. Illingworth a cordial invitation to join the Committee so that they might be thoroughly thrashed out, and if possible a common conclusion arrived at. **Professor Bone.**

Sir Robert Robertson, K.B.E., F.R.S., writes: **Sir Robert Robertson.**

In view of the adjourned discussion on Mr. Illingworth's

Sir Robert Robertson.

paper, I should like to say that if there had been an opportunity at the Joint Meeting on Thursday I would have stated, although disclaiming being an expert in coal, that as an investigation on physico-chemical lines the research appeared to me a very successful one.

I thought that he was particularly fortunate in obtaining a parallelism of the curves after elimination of the more readily volatile constituents given off at the lower temperatures.

It appears to me that it is from work such as this that important deductions can be drawn, and that these when confirmed may lead to important advances.

There is every reason to foster these investigations, as it is only by a scientific attack on the question, especially under the favourable conditions of proximity to the coalfield, and knowledge of your local conditions, that a basis of sound knowledge will be secured for further technical progress.

Mr. Illingworth.

Mr. Illingworth, replying to Professor Bone, thanked him for his kind invitation to join the Fuel Economy Committee, and accepted the honour. Mr. Illingworth asked Professor Bone how much of the coal in question was extracted by the neutral solvents.

Professor Bone.

Professor Bone: About 4 per cent. or 5 per cent.

Mr. Illingworth.

Continuing, Mr. Illingworth called attention to Dr. Wheeler's definition of the $\alpha$, $\beta$, and $\gamma$ compounds as given in the monograph on 'The Constitution of Coal.' The $\alpha$ compounds comprised that portion of a coal insoluble in pyridine. The $\beta$ (cellulosic) were compounds soluble in pyridine but insoluble in chloroform; they contained comparatively large amounts of oxygen and relatively small quantities of hydrogen; moreover, they had a smaller percentage of carbon than the original coal. These compounds did not melt, they yielded about 30 per cent. volatile matter, which contained large amounts of carbon dioxide and water; the liquid portions

contained little hydrocarbon, but large amounts of hydroxy compounds of a phenolic nature. This behaviour recalled that of cellulosic substances. The resinic or $\gamma$ compounds comprising that portion of a coal soluble both in chloroform and pyridine. These substances were rich in hydrogen and carbon, contained very little oxygen, and were emphatically differentiated from the previous substances, insomuch as they melted and became fluid at temperatures around 150°–200° C. They gave rise to a high yield of volatile matter, which consisted mainly of hydrocarbons, accompanied by very small amounts of hydroxy or oxygenated substances. This behaviour recalled that of the natural resins, and led Dr. Wheeler to define them as resinic. He (Mr. Illingworth) did not visualise them as acid anhydrides, carboxylic acids, lactones, or of the same chemical nature as damar, copal, kauri, or other natural resins. In his paper he suggested they might be protein residues. In his several researches he had shown that the proportions, stability, and volatility of these compounds determined the nature of the coal, its commercial usages, the nature of its coke, etc. Coke formation was determined by the resinic constituents. Throughout his researches he had found that so long as 5 per cent. of this class of substance was present the coal gave rise to a coke. He joined issue with Professor Bone on his contention that the resinic bodies were not the coking principle, and his remarks were also made in a spirit of friendly criticism, for truths could only arise by straightforward discussion between rival views. He would direct Professor Bone's attention to the tables in his paper, which gave the results of the pyridine and subsequent chloroform extractions of the coals and their residues considered in this research. Take the Y.O. coal, it was evident that this coal must be heated to a minimum temperature of 350°–400° C. before depolymerisation took place and the resinic substances were rendered soluble. It

Mr. Illingworth.

Mr. Illingworth. would be noted that the original coal showed practically nothing as soluble in pyridine, and he might add that heating this coal with pyridine for three weeks in sealed tubes only gave 0·8 per cent. pyridine soluble. Moreover, the Welsh coking coals all exhibited enhanced figures for the amount of pyridine soluble constituents after they had been slightly decomposed (say 1 per cent.), i.e. after they had become depolymerised. In the case of the No. 2 Rhondda extraction of the virgin coal with pyridine removed 4·93 per cent. resinic compounds, the extracted coal had not lost its coking qualities, but a further 6 per cent. of resinic compound was found in this residue when the coal had been heated for half an hour at 450° C. In this connection he would refer to his several papers in the 'Proceedings' of this Institute and in the 'Journal' of the Society of Chemical Industry, where it would be seen that every coal or residue therefrom which gave a coke contained as a minimum from 5 per cent. to 6 per. cent. of resinic substance. He contended he had established that the resinic matter was the coke-producing ingredient of coal. If it was not, what was? Maybe this type of substance would ultimately be resolved into several individual compounds; but was it not better to use such knowledge of the coal complex as we possessed and progress to generalisation, than to wait, maybe generations, till chemical individuals were isolated, which would only alter our generalisations in detail and not in principle? To sum up, he contended that his evidence justified and proved the view that to the resinic bodies must be ascribed the coking principle of coal; further, he would suggest to Professor Bone that he had not by neutral solvents removed the highly polymerised resinic matter from the coal he cited, and that the coking qualities of the residue from the extraction were due to these last-mentioned resinic substances.

Wheeler's terminology might be unfortunate from one

standpoint, yet it was decidedly symptotic. They had to realise there were three *classes* of substance into which they could resolve the coal complex; each class was typical, yet in the various species of coal each differed in stability, volatility, etc. **Mr. Illingworth.**

The discussion was adjourned.

# PROCEEDINGS.

## Ordinary General Meeting, Swansea. Thursday, September 30, 1920.

An Ordinary General Meeting of the Institute was held at the Royal Metal Exchange, Swansea, on Thursday, September 30, 1920, the President, Mr. J. Dyer Lewis, occupying the chair.

The minutes of the preceding Ordinary General Meeting, held at Cardiff, on July 23, 1920, were read and confirmed.

## Notes on a New Type of Colliery Tram.

By W. D. Woolley.

(Paper, *vide* Proceedings, Vol. XXXVI., No. 1, p. 165.)

**The President.** The President said the first paper on the agenda was that of Mr. Woolley, who had designed a tram intended to meet the requirements of the Coal Mines Regulation Act by endeavouring to keep the coal-dust off the roads as much as possible. The author had telegraphed to say he was unable to be present at the meeting, but the paper was, of course, open for further discussion. He supposed there was a little coal-dust in the mines of the Swansea area as well as in those of the eastern district—(laughter)—and Mr. Woolley's tram should interest them.

There was no response to the President's invitation for the re-opening of the discussion.

The PRESIDENT said the subject dealt with in the paper was of such wide interest and importance in the coalfield that he thought he was justified in keeping it open for consideration at the next meeting at Cardiff. **The President.**

The discussion was accordingly further adjourned.

## Recent Developments in Gas-Firing Steam Boilers and in the Utilisation of Waste Heat on the 'Bonecourt' System.

BY MAJOR W. GREGSON (LATE R.E.), B.SC., A.M.INST.C.E., A.M.I.MECH.E.

Major GREGSON, the author of this paper, replied to the discussion which took place at the last meeting of the Institute. **Major Gregson.** Mr. W. A. Chamen, he remarked, had asked a question as to the effect of bad water on the tubes of the 'Bonecourt' boiler. Mr. Chamen's idea was that, owing to the high evaporation, there was a large amount of water passing through, and they might expect to get rather more sediment than in an ordinary boiler. He had had under close supervision some gas-fired boilers in the London area where the water was very chalky and hard, and he found that when working near full load the tubes proved to be self-scaling. Apparently the rapid ebullition prevented the formation of layers of scale, the scale itself being broken up into small flakes which fell to the bottom of the boiler. Naturally, in the case of waste-heat boilers, or in that of gas-fired boilers not working on full load the evaporation was not so intense. In the case of a coke-oven gas-fired boiler working at a North of England colliery, where the feed-water was obtained from the mine and contained a lot of iron salts, its hardness factor of 24 being reduced to between 6 and 8 by a softener, it was found after twelve months' running that the tubes were coated with a very thin film of scale—too thin for chipping. This film was readily removed by the

Major Gregson.

addition of boiler compound; and he understood that by the occasional use of this compound no further deposits of scale occurred. It was impossible to totally remove the hardness from the water he referred to, owing to the rich concentrate which would thereby be formed in the water by the action of the reagents. Incidentally, he mentioned that in the case of a battery of water-tube boilers fired by coke breeze and working on the same water supply, frequent tube failures occurred owing to the bad water. Mr. Davison had called attention to the Skinningrove boilers, which, as was explained in the paper, were the first commercial 'Bonecourt' boilers built, in 1908. As he had pointed out, and as was mentioned in the report of the Nitrogen Products Committee, the original 'Bonecourt' boiler, of which the Skinningrove boilers are typical, had many inherent defects, chiefly of design, but the 'Bonecourt' boiler of to-day had eliminated those defects—in fact, they had been removed before the actual publication of the report of the Nitrogen Products Committee. Notwithstanding, however, those early defects, he believed no trouble whatsoever had been met with at Skinningrove in the boilers themselves, although packed with refractory material and getting high initial temperatures. What trouble there was occurred in connection with the fans and feed-water heaters. In the first instance this was due to the fact that the original fans ran at 4000 r.p.m., which was much too high for continuous running; the second trouble, in the feed-water heaters, was due to imperfect design. Mr. Davison had mentioned that the Skinningrove 'Bonecourt' boilers were idle when he was up there. The reason was that they were used during the war in connection with the manufacture of war chemicals, and the turn-over from war to peace requirements had not been completed, hence their being out of action; but it was understood they would shortly be in operation again. Mr.

James, of the Treforest School of Mines, had asked what would be the effect of oil in the feed-water of a 'Bonecourt' boiler. If any oil got deposited on the tubes, the general effect would be less injurious than in the case of oil on the flues of a Lancashire boiler, as the peak temperature in the 'Bonecourt' boiler was lower than the peak temperature in the Lancashire boiler. Mr. Reynolds questioned the safety of steam raising in thirty minutes in a 'Bonecourt' waste heat boiler working a gas engine. If Mr. Reynolds were referring to a boiler of the old type, i.e. of the Skinningrove type, it would most certainly not be safe to raise steam at that rate owing to the strains which would be set up in the boiler. But the newer types of 'Bonecourt' had a much greater ratio of length to diameter than the older types, and the same remark applied to the tubes. Hence, instead of comparing the 'Bonecourt' boiler to the Scotch marine boiler or a Lancashire boiler, a better comparison would be with the locomotive type of boiler but with lower peak temperatures, much greater flexibility being obtained. A good deal of experimental work had been done in this connection, and it had been found that rapid steam raising neither strained the boiler nor the material of which it was made. The fact that the peak temperatures of the gas-fired boilers were comparatively low, coupled with the now generally accepted theory that the walls of the tubes took their temperature more nearly from the water than from the gases, were undoubtedly factors which further assisted this proposition. They got a more or less uniform expansion throughout the whole boiler, which was helped by the excellent circulation. With the 'Bonecourt' boiler there was no difficulty in rapidly getting up steam, and there was no trouble from unequal expansions or strains. The other side of the question was that one of the greatest defects of most boilers when utilised for waste-heat recovery was that corrosion was

Major Gregson.

Major Gregson.

extremely difficult to prevent. This was due, firstly, to the fact that it was impossible in ordinary boilers to definitely fix the outlet temperature in order that this might always clear the critical temperature; and, secondly, to the long period of sweating of the tubes during steam raising from cold water. The 'Bonecourt' boiler allowed for exact temperature regulation at the outlet, and the short period necessary for raising steam reduced the sweating period to the minimum.

The President.

The PRESIDENT said he had received telegrams from Mr. Sugden and Mr. Reynolds asking that the discussion might be further adjourned to the Cardiff meeting.

Discussion adjourned.

## The Economics of the South Wales Coal-field.

BY HUGH BRAMWELL, O.B.E.

## Certain Chemical Aspects of the South Wales Coals and Coal-fields.

BY S. ROY ILLINGWORTH, B.Sc., A.R.C.S., F.I.C.

The President.

The PRESIDENT intimated that these papers could be taken into consideration together.

Mr. J. Henry Davies, F.G.S.

Mr. J. HENRY DAVIES, F.G.S., said when he saw the title of Mr. Bramwell's paper he thought that perhaps he would introduce it by an historical note on the rise of the coal-mining industry in South Wales, but when he found that it was confined to the present day he felt sorry that so competent an authority deemed it advisable not to do so. The paper was also limited to the eastern portion of the field and dealt with the valleys which ran roughly north and south. From the Neath valley to the west had been and was still important when dealing with the economics of the South Wales coal-field. The rise of Neath,

Swansea, and Llanelly was intimately connected with the geological structure of South Wales. The sea had breached the limestone between Tenby and Gower, and between Gower and Porthcawl, forming sheltered bays and opening up highways for large steamers to enter into the heart of the coal measures which contained the best anthracite coal. The rivers Neath, Tawe, Lougher, and others had opened passages so that canals, roads, and railways might be constructed right up to the northern end of the coal-field. The ports at the mouths of these rivers enjoyed the advantages of easily available supplies of raw materials; the presence of anthracite coal for power and export; and excellent harbour facilities for export to home and foreign markets.

Mr. J. Henry Davies, F.G.S.

The history of South Wales might be divided into two periods, the first reaching backward from 1745 to the earliest times, and the latter coming forward to the present. The first period might be called the Pre-Coal Age and the second the Coal Age. The strength of South Wales lay in its coal, and the steam-engine above all other agencies had been the means of bringing it out. The population increased rapidly as the means of subsistence multiplied, and the magnificent store of coal in South Wales was the secret of its rise to wealth. There were many people to-day who, deploring the shortcomings of machine industry, imagined that the rise of the mining industry brought death with it. The actual fact was the reverse. The growth of power based on coal was the giver of life. Prior to the Coal Age there were no canals, roads, nor railways in South Wales. Coal worked in Carmarthenshire and Pembrokeshire was carried on pack mules to Milford, Tenby, Haverfordwest, and Carmarthen. It was interesting to examine the figures of exports. In the year 1745, 1516 tons were exported from Milford to London; 298 tons from Tenby and Haverfordwest, and 43 tons from Carmarthen. No coal

Mr. J. Henry Davies, F.G.S. was sent from Glamorgan, but five years later Swansea and Neath began exporting. In the year when the English and the Prussians fought against the French at Waterloo, Cardigan was the chief port in South Wales. It exported five times more than Cardiff. In 1829 Cardigan exported about fifteen times the value of coal as compared with the whole of Glamorgan, but in 1833 the tables were reversed, Newport being the highest, exporting 440,492 tons; Swansea a good second with 360,000 tons; Cardiff, Llanelly, and Neath being third, fourth, and fifth respectively. In 1870 Cardiff was far ahead of the other ports, and to-day it was one of the chief ports in Britain. From 1870 to 1914 the export trade of coal had risen from 13 per cent. to 33 per cent. of the total output. South Wales exported 40 per cent. of the total shipment of coal from the United Kingdom. In addition to the natural difficulties mentioned in the paper, in all the collieries in the western part of the coalfield there was a constant struggle with three systems of faults, viz.: N.-S., E.-W., and the W.-S.-W. faults. The output of coal at times became seriously reduced, though the same number of men was employed—with bad results financially. They had to thank Mr. Bramwell for giving them freely, in the true scientific spirit, important information and data to work upon, which were more valuable than theories.

Mr. George Roblings. Mr. George Roblings said he was pleased to see that Mr. Illingworth had extended his investigations to the western end of the coalfield. There were many problems relating to anthracite that awaited solution. Take the briquette for example: the agglomerate burned away before the coal.

The President. The President: When anthracite alone was used?

Mr. Roblings. Mr. Roblings: Yes. He could not believe that it was beyond the ability of the present-day chemist to discover a remedy for that, either by using known material or by a new treatment of known materials. Incidentally such an accom-

plishment would help to put to good use the large heaps of duff that lay about their pit tops. There had been times when they could not get people to take it away only a few years before the war, and since then it had been found difficult at times to get rid of it. There was the difficulty, too, of igniting anthracite for steam raising. They were compelled to use forced draught at comparatively high pressure, and when the smaller sizes were used large quantities were blown into the flues unconsumed. **Mr. Roblings.**

What Mr. Illingworth had found in the laboratory they had found in their practical work. They had not found the reason why, but Mr. Illingworth has been able to throw light on the subject, his diagram being particularly interesting. The principal point, however, which he (Mr. Roblings) would like to take had reference to the formation of anthracite. It was a coincidence that he incidentally referred to the subject in his paper on the gas and dust outburst at Ponthenry Colliery.

He experienced, however, some difficulty in following Mr. Illingworth, as he seemed to mix up the *in situ* theory and the drift theory. Referring to changes from east to west, which he tentatively attributed to the elimination from the matrix from which the coal was formed of the protein and cognate substances that constituted the resinic portions of the coal, Mr. Illingworth laid it down that:

'This elimination has taken place due to bacterial agency, either in the original matrix *in situ* or in regional swamps; and subsequently selective deposition of the altered matrix has taken place, the lightest portions being carried farthest and a gradation in density of the deposited mass has resulted from shore line out to deeper water.'

He (Mr. Roblings) does not see the difference between deposition *in situ* and deposition in regional swamps. He (Mr. Roblings) was not clear whether Mr. Illingworth was referring here to powerful currents washing through the regional swamps.

Mr. Roblings. If so, one would like to know upon what evidence it is based, as there is little evidence of such a condition of things in the coal seams proper: there are certainly washouts which indicate running water, and which have existed after the deposition of the vegetable matter forming the seam: these may be strong currents, but they do not assist us in this matter.

He (Mr. Roblings) would prefer to consider that the water in these swamps, in view of their great extent, must have been nearly stagnant, or at least possessing such a slow rate of movement, together with the obstacles which must have been presented by the vegetation, as to be incapable of exerting any transportive power, and therefore unable to carry out the selective deposition as suggested by Mr. Illingworth. Further, stagnant swamps with the organic matter well covered by water would present favourable conditions for decomposition, and this could be brought about by a class of bacteria called anærobes, which he was informed do not require oxygen to carry out their work, and he was of the opinion that these had a greater effect in causing the changes than those requiring oxygen and known as ærobes.

The President. The President said, with regard to the chemistry of anthracite coal, a good deal of research work had been going on for some years by Mr. Evans, a gentleman appointed by the late Lord Rhondda, and who, he understood, had succeeded in making a briquette wholly of anthracite, which burned as well as any other briquettes. It was made in the form of ovoids, and although not yet on the market was being turned out at a small factory in London. The papers of both Mr. Bramwell and Mr. Illingworth were admirable contributions, and in closing the discussion upon them he moved a cordial vote of thanks to the authors. (Applause.) Should Mr. Bramwell and Mr. Illingworth wish to reply to comments upon their papers they would be able to do so in writing for inclusion in the 'Proceedings.'

# MINING WARFARE.

By Capt. D. Ivor Evans, M.C., late 251 Tunnelling Coy. Royal Engineers.

# MINING WARFARE.

By Capt. D. Ivor Evans, M.C., late 251 Tunnelling Coy., Royal Engineers.

During the world war of 1914–1918 a very large number of innovations in the history of warfare became very prominent, not the least of which was Mining Warfare. Mining engineers and miners from all parts of the British Empire where mining is carried on were extensively occupied in this work. South Wales was generous in its contribution of officers and men, and as the South Wales Institute of Engineers was well represented in that branch of His Majesty's Service which became responsible for the very extensive mining operations along the whole of the British Front, it is thought that some record of such operations should be incorporated in the Proceedings of the Institute. With this object in view, the writer submits the following account of the part played by miners in the war, and hopes that the many other members of the Institute, who served as officers in the Tunnelling Companies of the Royal Engineers, will add their experiences to this paper, so that there may be a fuller and more complete record.

It is not pretended that the paper contains much of scientific or technical value, or that it is anything except a general descriptive narrative of such mining operations as came within the scope of the writer's personal observation. It may, however, serve to indicate to some little extent the contribution of mining engineers and miners towards the successful conclusion of a war in which mining played a very prominent part,

reaching its zenith in the stupendous operations at the Battle of Messines Ridge, when nineteen mines were exploded, containing in the aggregate between 400 and 500 tons of high explosive, resulting in complete paralysis of the enemy for the time being.

In the early part of 1915, after the first onslaught of the enemy upon the Channel Ports and Paris was held in check, a period of immobility ensued, which lasted until the Battle of the Somme in July 1916 and in some parts of the line even until the middle of 1918. The Allied and the enemy forces settled down within a short distance of each other and dug in. There was practically a continuous line of trenches from the sea to Switzerland, garrisoned all along its length by the Belgian, British and French armies on the one side and the German army opposite. The distance between the trenches varied between 100 and 300 yards, and in some cases the trenches were very near, not more than about 50 yards apart. The line was an extremely sinuous one, as perforce it had to be dug in wherever the circumstances allowed it. Originally there was merely a ditch hurriedly dug forming the front line, which afforded but little protection to the occupants. When the condition of stalemate became general, the trenches were deepened and strengthened, additional trenches were dug behind the front line, forming a support line and reserve lines, and in many places there were half a dozen or more lines of trenches behind the front line. The same course was adopted by the enemy. Communication trenches were constructed at intervals of between 200 and 300 yards to enable troops to pass to the front and intermediate lines. This trench system for a long time formed the home of the Allied and enemy troops. Constant work was involved in improving, strengthening and draining the trenches, notwithstanding which they were frequently very dilapidated. The front line trenches were

strongly manned in the earlier stages of trench warfare, while troops in reserve occupied the support and reserve trenches. Such was the state of affairs when mining operations were introduced about the beginning of 1915. The enemy with his usual ingenuity conceived the notion of driving underground galleries from his front line trenches and extending to points underneath our trenches. When the galleries had been driven to such an extent that he estimated they would undermine our trenches, he formed a chamber at the end, charged it with high explosive, and at the opportune moment—when everything seemed to be going along normally—he fired, causing considerable surprise and consternation amongst the troops forming the trench garrison, many of them being blown up. These operations naturally produced a very demoralising effect. Troops in the front line were constantly in a state of nervous tension, exposed as they were to rifle and machine-gun fire, sniping, desultory shelling, and very frequently intense bombardments, sometimes accompanied by minor raids and attacks. Therefore, when mining operations began, the situation became very much more unpleasant, as this new danger was unseen and frequently unsuspected, and the troops never knew at what moment they might be blown sky high. The firing of a mine was invariably accompanied by an intense artillery bombardment and frequently by a minor raid or attack, and the consequence was that troops in the line became very 'nervy' when mining was suspected.

Measures had to be taken at once to counteract the effect of this new disturbing element. Suitable men from the division holding the line were selected, and detailed to undertake counter-mining operations. In a very short time it was found that experienced miners were necessary, and men employed in the collieries of this country were asked to volunteer for service in this branch of warfare, which was properly

designated a 'Suicide Club.' Tunnelling Companies of the Royal Engineers were formed, and to induce men with knowledge of mining to join the Tunnelling Companies, special rates of pay were established at 6*s*. per day. The response to the call for miners—notwithstanding the hazardous nature of the work—was exceedingly good. Almost as soon as the companies were recruited in this country they were shipped off to France, as the situation was becoming very critical and brooked no delay. There was no time for training in the usual military duties, and the fact that these men had knowledge of mining was deemed sufficient. A great number, in fact nearly all (both officers and men), had no knowledge of the elementary rudiments of military training. They were able to form fours with difficulty, and that was about all. They had no notion in the majority of cases of handling or using a rifle, yet they were armed troops and if necessary had to take their places with the infantry. The need for skilled men was so great that the long course of training through which most soldiers passed was dispensed with. In many cases the miners were working in the front line within a few weeks of joining the Army. It was rather trying to these men, but there was no other alternative, as the work had to be done and done quickly. In many parts of the line the enemy miners were underneath our trenches. Consequently, our counter-mining operations opened under very serious disabilities, and to be of any use at all the operations had to be undertaken immediately, or the armies would be faced with the alternative of abandoning the lines which they had fought so hard to establish.

Before the end of the war there were about 30 Imperial Tunnelling Companies, 3 Australian Tunnelling Companies, 2 or 3 Canadian Tunnelling Companies, 1 New Zealand Tunnelling Company, and 1 Portuguese Tunnelling Company. The establishment of a Tunnelling Company consisted of

19 officers and about 340 other ranks, but as mining was particularly active in 1915 and 1916, some companies had a strength of between 700 and 800 all told, the strength having been made up of miners who had already enlisted in the infantry and were detailed from their battalions for mining work with the Tunnelling Companies, and in addition carrying parties of 300 to 400.

The original raw material of the Tunnelling Companies very quickly developed into efficient soldiers, as during the time the men were not actively engaged in mining they had to undergo the usual training of the infantryman, and finally developed into exceptionally well-trained units, both as regards their own special work of mining and as fighting troops. The men were drafted from every coalfield in the country, and every mining district in the Colonies contributed its quota for this special work. Amongst the officers there were representatives of every Mining Institution throughout Great Britain and the Colonies. The South Wales Institute of Engineers was very well represented. Many of the officers and men might well be considered to be above the military age, but they all entered upon their work with surprising keenness. There was an instance of a sergeant in a Tunnelling Company working in the same trench as his grandson, who was a private in the battalion garrisoning the line.

A Tunnelling Company was commanded by a Major responsible for the work of the company as a whole. Each company was divided into four sections under the command of a section commander and three or four subalterns. Each section was divided into four sub-sections or shifts. The company would be responsible for mining operations on the length of perhaps a mile or two of front, part of which was allotted to each section. The work was continuous day and night without a break. The following description may be taken as typical of

the work of a section. At about 2.30 A.M. No. 1 shift was awakened; breakfast at 3, and at 3.45 the shift fell in on parade at the permanent headquarters of the company, generally situated at a point about two or three miles behind the front line. Rifles, ammunition and gas helmets were inspected, each man was loaded up with timber, tools, bags, pumps, rescue apparatus, rations for the day's work, and whatever else may have been required during the shift. The men with their loads were run up in lorries to the nearest possible safe point to the trenches that the lorries could be taken. From this point forward they walked perhaps through half a mile or more of communication trenches, carrying their loads in addition to their usual equipment of rifle, bayonet, gas masks, etc. The point where work was in progress would be reached between 5.30 and 6 A.M. The N.C.O. in charge of the shift was met by the officer on duty and given instructions as to the disposal of his men, after which the men coming on duty relieved the men who were completing their shift. As soon as the relief was completed, the men who had just finished their shift went back to headquarters. The length of the shift was twelve hours. At about 6 o'clock in the evening No. 1 shift would finish and be relieved by No. 2 shift, who would work for twelve hours. No. 2 shift would be relieved by No. 3 shift, and No. 3 shift in turn by No. 4 shift. Each man's routine of work therefore consisted of an actual shift of twelve hours in the trenches plus two hours going up and two hours coming back, making sixteen hours in all, with thirty-two hours back at headquarters before going again to the trenches. During the period spent at headquarters there were multifarious duties, including physical training, drilling, bayonet fighting, physical drill, the usual fatigue duty in and about camp, and recreation. The officers' tour of duty consisted of forty-eight hours in the trenches and usually forty-eight hours back at

headquarters. At the headquarters of the company there would be a headquarters section consisting of carpenters. sawyers, smiths, bootmakers, tailors, cooks, storemen, etc. The company was always in the line and never pulled out for a rest, as was the case with the Infantry and Artillery. A company was frequently on the same front for a very long time. In one case the same company occupied practically the same part of the line from October 1915 until April 1918—two and a half years—without a rest. Generally this was the daily routine. Work went on continuously without a break and often under exceptionally trying conditions, particularly during the winter months, when the trenches were almost impassable and the mines frequently half full of water, and even walking through the communication trenches to the front line was as hard as an average day's work.

At the outset of mining operations by the Allied troops the work in most places was purely defensive and directed with the object of preventing any further inroads by the enemy upon the existing trench systems. Many parts of the line were undermined, causing a feeling of great insecurity to the garrison which constantly occupied the trenches and going a long way to destroy the morale of the men, especially as in some cases mines were fired not only under our front lines but even under the support and reserve lines. To counteract the advantage which the enemy held, it was necessary to construct a mining system which not only cut off the enemy galleries but would also prevent any further encroachment. It may well be imagined that this was an exceptionally difficult job. Every operation of our miners was liable to discovery by the enemy. The gallery had to be pushed forward anyhow, inasmuch as the information available of the position of enemy galleries was purely conjectural. During this work there were exciting incidents daily, and many are the cases when our galleries

came in contact with the enemy galleries. The aim of counter-mining lay in the construction of a mining system well outside our front line trenches in 'No man's land,' so that there would be very little possibility of enemy mines being pushed forward under our lines without first encountering our mining system. In order to achieve this object it became necessary wherever it was thought there were enemy galleries existing to blow mines against them and if possible to destroy such galleries. Immediately after firing a mine our galleries were driven a step further forward, and in this way, by quick driving and counter-mining, we were able to establish a mining system outside our front line and towards the enemy line. The work was slow and laborious, and yet had to be performed with the greatest possible speed. In the early days quiet working had to be set aside and risks had to be taken very freely. as the exigencies of the situation demanded the counter-mining to be as expeditious as possible. This stage in mine fighting was extremely hazardous, and there were, of course, innumerable casualties amongst the miners. After considerable trouble the position eased to some extent, as we were able to construct galleries more or less parallel with the front line trenches, and as time went on other galleries were driven out towards the enemy lines, so that a complete defensive system was established. When this work was completed, there was a fairly adequate defence against enemy mining and the trenches became more secure from the operations of the enemy.

Subsequently from this defensive system it became possible by cautious working to extend the galleries towards the enemy mine system and under his trench system, thereby producing the same sense of insecurity in the enemy garrisons as was originally produced by him in our own garrisons.

The lay out of the mining system consisted of main galleries driven at right angles to the front line of trenches. commencing

frequently in the front line itself and extending towards the enemy lines. These main galleries were two or three hundred feet apart and connected together by lateral galleries running more or less parallel with the trenches. From these lateral galleries, as they were termed, at intervals of about fifty or sixty feet, listening posts were constructed consisting of smaller galleries driven towards the enemy line. These were, of course, driven out as far as the circumstances would allow, and it was in these listening galleries that charges were laid when it was thought that the enemy mining system was approaching. In some cases, where time and circumstances permitted, the mining galleries would possibly commence in the support line, but in the majority of cases they were placed in the front line itself, and connected up with the support lines later. Sometimes the galleries took the form of slants driven outwards from the front line. In other cases, where the necessary depth of cover could not be obtained by this method, shafts were sunk of varying depth and the galleries driven out from the shaft bottom in the same manner as is done in ordinary coal mining. In the case of a slant, the point of commencement having been selected, the gallery was driven at a declination varying from one in six to one in one, according to the depth of cover required. When the necessary depth was reached, all galleries were constructed more or less on the level. The sizes of the main galleries were usually about 4 feet 6 inches high by 2 feet 6 inches wide and timbered according to the nature of the ground. In some cases timbers were 2 or 3 feet apart—in other cases quite close. The timber sets invariably consisted of flat timber 6 to 9 inches in width by 2 to 3 inches in thickness, forming a complete rectangular frame. The two props were plain and the cap and the cill had cleats nailed on, leaving notches at each end for keeping the legs in position. The roof and sides were supported by lagging fixed behind the sets. This was the usual method

of construction of all the galleries. The listening posts were usually about 2 feet by 4 feet. In view of the necessity for quiet working, special tools had to be devised, as the pick and shovel method was too noisy. When the galleries were in clay or bastard chalk, a tool called a pushpick was usually employed. This tool consisted of a small triangular spade fixed to a short haft. This pushpick was cautiously forced into the ground at the face and then used as a lever to dislodge small blocks of clay or chalk. In some cases, when extreme silence was required, a short bayonet was mounted on a wooden shaft and used in the same way. A short spade was sometimes employed in clay. The miner, in using this spade, lay on his back, forced the spade into the clay with both feet, and handed the dislodged block of clay over his shoulder to another miner standing behind him. The spoil was filled into sandbags and passed out from the gallery from hand to hand or drawn along the floor, in which case it was usual for the drawer to work in bare feet or in rubber boots. All conversation had to be carried on in whispers. A tramway was generally arranged in the lateral and main galleries with wooden rails. Small rubber-tyred trolleys were used to carry the sandbags to the surface. The usual rate of driving by quiet work in clay was from 4 to 6 feet of gallery in 12 hours, including timbering. If quiet working was not essential, the rate of driving by good workmen amounted to 10 feet in 12 hours. One instance occurred of a drivage in clay 6 feet high by 4 feet wide and 92 feet in length, timbered throughout, being completed in 48 hours, and during 1917 one Company only used to drive on an average 1000 feet of new gallery each week.

The entrance to the main galleries was protected by a kind of roof fixed across the trench, formed of timber with corrugated iron and sandbags to give some protection against shell fire and splinters. The shafts were usually about 4 feet square

and were lined by timber frames at intervals of 2 or 3 feet, the sides being kept from falling by close lagging behind these frames. In other cases, where the strata was water bearing, the shafts were tubbed with light steel tubbing. Over the shaft head a penthouse was erected consisting of a timber frame-work forming a kind of house in the side of the trench with layers of sandbags laid on the top. In some cases where shelling was heavy, considerable trouble was experienced owing to the shaft heads being destroyed, and it became necessary to construct substantial shelters consisting of reinforced concrete with walls of 3 to 4 feet in thickness, which would withstand a direct hit by a moderately heavy shell. Another type of penthouse adopted in the writer's company was constructed of semi-circular corrugated iron shelter covered over with heavy rails, broken brick and earth. To construct this shelter it was necessary to excavate a hole about 20 feet long by 8 feet wide. At the bottom of this excavation a heavy frame of timber baulks was laid to form a foundation for the semi-circular corrugated iron structure. When this had been erected, the layer of rails--ordinary railway weight--was laid over the shelter about 4 feet below the original ground level, skin to skin, but without bearing directly upon the top of the corrugated iron. Longitudinal bearers were laid over these rails, and then another layer of rails, skin to skin, on the bearers. On top of these rails were laid 3 or 4 feet of brickbats, obtained from ruined houses in the vicinity, and the whole was covered with earth, so that the original level of the ground would appear undisturbed to any enemy observer. The floor of the penthouse was strengthened by reinforced concrete, and the shaft, which in this case was a circular shaft lined with steel tubbing, was sunk. The air space between the two layers of rails, together with a broken brick covering, afforded most effective protection, and a direct hit on this

shelter by an 8-inch shell failed to destroy it. In this particular instance the whole of the work was done within 100 yards of the enemy trenches, and was completed without any apparent disturbance of the original level of the ground. It will therefore be easily realised that this was not a small undertaking, especially as another factor unfortunately interfered with the construction and made it more difficult. The ground where this structure was made was soft clay, and the excavation could not have been done without timbering, which was rather a difficult operation to carry out without being observed. Advantage was taken of a spell of frost to make the excavation without timbering. There were three of these structures made. In two instances the corrugated iron penthouse was erected without any difficulty, but unfortunately in the third case the thaw set in when the foundation for the corrugated iron shelter had been completed, and the whole of the sides of the excavation ran in, forming a big puddle of mud. However, the job was tackled and was successfully completed. The existence of these structures, with two other similar structures constructed of heavy reinforced concrete, was a very important factor in the successful defence of Givenchy by the 55th Division during the enemy offensive in April 1918.

One of the principal difficulties in connection with mining was the disposal of spoil. A great quantity of earth was excavated, which had to be so disposed of as to be invisible to the enemy. This was a matter of extreme difficulty, especially if the main galleries were in chalky ground, as the chalk when brought out to the surface was very conspicuous, and its presence immediately indicated to the enemy that mining operations were in progress. Various methods were adopted for dealing with this spoil. The usual method consisted of spreading it evenly over a wide surface and covering

it over with surface clay or with camouflage consisting of wire netting covered with coloured canvas to resemble as nearly as possible the general characteristics of the ground surface in the vicinity. In some instances a trench was made with a light tramway at the bottom; the trench was covered with camouflage, so as not to be visible to enemy aerial observers, and the spoil was removed in trollies to a point at a safe distance from the scene of the mining operations and dumped there, drawing, of course, periodical bursts of harmless shelling from the enemy. As experience was gained the camouflaging of the spoil became a fine art. Usually the spoil was brought from the mines in canvas bags, technically called 'sandbags.' At one time, when mining was very active, upwards of 35,000 bags weekly were used by one company alone. These bags were filled at the face and carried by hand to a point where a trolley running on wooden rails could be used without any risk of the sound being heard by the listening miners opposite. The spoil had invariably to be disposed of by night, as any movement by day was absolutely impossible.

During the wet weather, especially in the shallow mining systems, the question of drainage became very serious. It was imperative that the mines should be kept open, and the only means available of keeping them free of water was by hand pumping, the ordinary form of contractors' hand pumps being usually used with armoured rubbered hose-pipes. At a later stage in mining operations, when underground subway and dugout systems had been constructed, electric pumping was adopted, the generating plant consisting of small motors actuated by petrol engines.

Candles were used for lighting the mines, and latterly 'Ceag' electric hand lamps, but usually these were only employed in connection with mine rescue work. At one period in 1917, when the writer's company was very actively engaged, the

consumption of candles amounted to 280 lb. daily. The subways and dugout systems were lit electrically.

The ventilation of the mine was often a difficult matter, especially in long lengths of offensive galleries. Here again, hand pumps were used, and latterly small fans. Originally the ventilation was effected by the ordinary blacksmith's bellows attached to rubber hose-pipes. These bellows were found to be very cumbersome, and were subsequently replaced by two types of air pump—the Holman Pump and the Keith Blackman Blower—usually fixed in the trench in the open or at some point in the mine where there was always a fresh current of air. The ventilation was particularly important, especially after mines had been exploded, as the whole system would then be frequently full of carbon monoxide formed by the explosion of large quantities of high explosives.

In the earlier stages of mining the explosive used was guncotton, as up till then this explosive was the one with which the Royal Engineer units were equipped for ordinary demolition work. This was soon found to be unsatisfactory, as it produced very large quantities of carbon monoxide, with the result that it was very difficult to clear the galleries of this gas after an explosion; and as it was very important that work should be resumed almost immediately, the use of guncotton was abandoned.

Ammonal was the explosive which was finally adopted, as it was found to give the best results, although even this explosive gave off a considerable quantity of carbon monoxide.

Other explosives used were Amatol, Blastine, and Sabulite. Explosives were used in very large quantities, and even in shallow mines anything from 2000 lb. to 5000 lb. was an ordinary charge for a mine. The quantity of explosive necessary was estimated by a formula which involved the depth of cover and the diameter of the crater formed after the ex-

plosion. This estimation of the amount was very approximate, but it may be taken for certain that when a mine was to be blown, any error in the quantity was always on the large side, so that no mistake might be made as to the result. Ammonal was usually provided in hermetically sealed tins containing 50 lb. By this means the explosive was kept dry, and the size of the tin was such that it could be fairly easily handled under the difficult conditions of the mine galleries. Under certain circumstances the charge was laid without opening the tins, two or three tins in the charge being cut open for the reception of the detonators. This method of laying the charge in the tins was open to objection, as handling in a gallery, especially where the enemy galleries were fairly near, was a noisy process, and the fact that a mine was being charged was liable to discovery by the enemy. A safer and more usual method was, if the mine was dry, to fill sandbags with the explosive, each bag containing about 25 lb. Where the mine was wet, special rubber bags were used which were waterproof and prevented the explosive deteriorating from the damp.

When it was decided to load up and fire a mine, the process of charging was as follows :

The explosive was assembled in a dugout in the trench system which acted as a magazine. Usually large quantities of explosives were stored in this dugout, so as to be ready for any emergency, as it often happened that a mine had to be charged and fired at very short notice. A couple of men would be engaged in filling up the sandbags or rubber bags, as the case might be, from the tins. When the requisite amount had been prepared this was carried by a string of men, handing one to the other, and extending to the mine entrance nearest to the gallery in which the mine was to be laid. There would be another string of men stretched along the mine gallery

up to this point, and when all was ready the bags would be passed from hand to hand to the officer whose duty it was to lay the charge himself. He would be situated at the face of the gallery, and for an hour or two whilst the bags were being passed up and laid in position he had to work exceptionally hard, as apart from the labour involved in handling the bags the atmosphere was very often foul, the space in the gallery was restricted, and more often than not there would be 6 to 12 inches of water or mud on the floor of the gallery. After the full quantity had been packed in the face of the gallery the officer fixed the detonators. Usually in a small charge perhaps half a dozen or a dozen detonators fitted with gun-cotton primers were connected in series and distributed in the body of the explosive. It was necessary to use detonators prepared for firing by fuse as well as for electric firing, so that in the event of the connections becoming loose or the wires being broken, the fuse could be fallen back upon as a means of firing. When firing electrically the wiring was done in duplicate, which was another precaution in the event of the one set of leads becoming damaged. When the detonators, leads and fuses had been properly fixed, the circuits were tested by means of a dry cell, galvanometer and Wheatstone Bridge, and the leads unrolled out of the mine to the firing point. After placing the charge, and in order that the full effect of the explosive might be produced, the gallery would be tamped much in the same way as an ordinary shot-hole underground is tamped. This tamping was done by means of sandbags full of earth. There usually would be innumerable sandbags produced from the spoil obtained in driving the galleries. These sandbags would be passed into the mine on the same system as the explosive, that is, by a string of men a couple of yards apart. These were laid up against the charge and the gallery filled for perhaps a distance of

20 feet of its length, and the bags rammed in as tightly as possible. After the first 20 feet or so, an air space of about 4 or 5 feet was left, and then another length of tamping for perhaps another 20 feet of gallery, then a further air space and another 20 feet of tamping. The amount of the tamping had to be judged by the proximity of the gallery to other galleries and by the size of the charge. Charging the mine with explosive and tamping was exceptionally severe work, and often had to be performed under the most trying circumstances.

In one instance, an enemy miner struck his pick into a gallery while the officer was laying the charge. The enemy gallery was on a slightly higher level than our gallery, and hostile working had been distinctly heard for some time. The officer immediately put out his light and lay quite still, passing a word back to the men that they were to keep perfectly quiet. They lay perfectly still for some time, and in a few minutes the German mining officer, to whom the incident had probably been reported, came along and showed his electric torch through the hole, examined the place, and evidently got frightened and went away. As soon as the officer (who meanwhile had been lying in the gallery as quietly as possible) was satisfied that the enemy miners had retired, he immediately tamped the mine very hurriedly and fired, with the result that for some days the enemy operations at this point were suspended.

Exciting incidents of this kind happened frequently. There have been many cases where enemy mines have been exploded while the process of charging and tamping was in progress, resulting in heavy casualties.

When the whole operation of charging had been completed, the leads would be unwound to some point in the trench which afforded the best cover from shell fire, the circuits would be tested again by the galvanometer, a length of safety fuse

would be fixed to the instantaneous fuse, which latter was usually employed in the long leads, and when everything was ready the officer would report to the Infantry officer holding the line, and the time of firing would then be definitely arranged. About five minutes or so before the time of firing, an officer would be detailed from the Infantry companies in the neighbourhood, and this officer would report personally to the mining officer that the trenches were clear of men, as naturally it was necessary when firing that there should be no men in the trenches within a radius of several hundred yards. The exploding of the mine was usually accompanied by concerted action on the part of the Artillery, and sometimes on the part of the Infantry, who might carry out a raid or a minor attack upon the enemy lines. In such event all watches would be synchronised, the zero hour fixed, and all would be waiting. The ends of the leads would be attached to an electric exploder similar in principle to the exploder used in ordinary shot firing but of a larger type, and at the given moment the mining officer would press the plunger. If the circuits were satisfactory, the mine exploded instantaneously. If not, the officer fell back upon the instantaneous and time fuses; but usually, if the work was carefully done, the electric firing was satisfactory. The mine would go off with a tremendous roar, an earthquake effect would be produced in the neighbourhood, and a huge quantity of earth would be blown up for tremendous distances into the air, and for some little time afterwards the sound of falling earth was predominant. A large crater would be formed, and as soon as the earth had fallen the Infantry would immediately re-occupy their positions and carry out the operation of what was known as consolidating the crater, that is to say, they would occupy the lip of the crater nearest their own trenches, dig in so as to afford themselves some shelter, and subsequently, when the opportunity lent itself, they would

connect this point, where they had dug in, with the front line trench by means of a sap. If practicable, the lip of the crater would be held as a bombing post and would afford a kind of advance trench, forming a vantage point for observing and checking the activities of the enemy. Immediately after the mine explosion, and almost simultaneously, the Artillery would open out a bombardment upon the enemy trenches in the vicinity of the mine, thus adding to the consternation which the explosion of the mine had already produced. This bombardment would possibly be maintained for a quarter or half an hour, and under its cover the Infantry would carry out their consolidation of the crater lip. Naturally all this process was not unaccompanied by retaliatory measures on the part of the enemy, and it was surprising how quickly after the mine had exploded the enemy was able to bring his artillery to play upon the danger point.

In the case of defensive mining, such mines as have just been described were frequently blown for the purpose of destroying suspected or known enemy mining work. In some cases galleries were driven with the object of springing a mine under some well-known enemy strong point, such as a machine-gun nest or a trench mortar position which had been troublesome to the Infantry. In the case of offensive mining, the work of preparing the mines might have extended over a period of many months, involving a great deal of patient labour, and possibly the mine would be well underneath the enemy trenches. This was the case in Messines, when the miners had been busily engaged for lengthy periods and the mines which were laid were situated at considerable distances inside the enemy lines.

As the result of the mine explosion a huge crater would be formed, the diameter of which varied in accordance with the size and depth of the charge. A crater of 100 feet in

diameter and 20 or 30 feet deep was usual in shallow mining systems. In the deeper mining systems the craters were very much larger and deeper. The forming of the crater was the direct effect of the mine. Another effect would be to cause extensive damage to the enemy mining system and trench system, particularly the former. If a mine was successfully placed and fired, the work involved in reconstructing the enemy galleries was very considerable, and often resulted in the abandonment of mining operations in the immediate locality. Within a few hours after the explosion our own mining systems would be explored and tested for gas, and work resumed at once in extending the galleries adjacent to the mine still further towards the enemy lines. It was considered to be fairly safe to do this for a few days after the mine had been fired, as it was a fairly safe conjecture that counter-mining by the enemy would not be carried out immediately. When he did commence to counter-mine our galleries would have advanced to better tactical positions, and of course to our advantage, as we were then in a better position to detect any fresh enemy operations. If, however, the enemy mining systems were not seriously damaged, his usual practice was to charge a mine in the nearest gallery available and fire, so as to prevent us extending our mines too near to his lines.

This was the kind of operation that went on constantly during 1915 and 1916, when mining was particularly active. On a front occupied by one particular Tunnelling Company, as many as sixteen mines have been exploded in nine days, and in one part or another of that same front, within a limit of about three miles, it may be taken that three or four mines per week was an average number, and this lasted from October 1915 until the autumn of 1916, when extremely active mining died down to some extent.

The effects produced by enemy mines were often serious. Notwithstanding the vigilant measures adopted to discover

symptoms of mining activity on the part of the enemy, hostile mines would be sprung at unsuspected moments and casualties were frequent. The bodies of many miners which will never be recovered lie buried deeply along the trench systems. Very often the patient work of weeks would be destroyed, and the recovery of the defensive system by the reconstruction of new galleries was very tedious and laborious, apart from the dangerous nature of the work. Furthermore, the explosion of enemy mines had the effect of flooding the mining system with carbon monoxide, which condition made the recovery of damaged galleries an extremely difficult task. Casualties from carbon monoxide poisoning were very general, and steps had to be taken to provide rescue work.

A very complete system of mine rescue organisation was evolved. Mine rescue schools were established, where officers and men could be trained in the use of rescue apparatus in the same way as men are being trained at rescue stations in the coalfields of this country. Squads of mine rescue men were formed in each Tunnelling Company, all of whom were thoroughly practised in the use of the 'Proto' and 'Salvus' mine rescue apparatus under the most trying conditions. Such men were very carefully selected and put through a strict medical examination as to their general physical fitness. Rescue stations were established in the trenches, where 'Proto' apparatus was maintained ready for immediate use; and there is no question about it—hundreds of casualties were avoided by the expeditious way in which the mine rescue squads performed their duties. Weekly practices were held in the mines, and the squads became very efficient. The work was rendered more difficult by the fact that the galleries were so small, and even under the best of circumstances it was with difficulty that a man wearing the rescue apparatus was able to creep along.

The rescue stations in the trenches were equipped with

oxygen reviving apparatus, stretchers, blankets, ropes, 'Ceag' electric hand lamps, canaries and white mice, primus stoves for warming coffee, etc., and in fact everything with which a modern mine rescue station is equipped. There was a further difficulty which the mine rescue men had to contend with, and that was due to the fact that whenever a mine was exploded the trenches were very heavily bombarded, and the men had to make their way to and from the rescue stations under very heavy shell fire, as of course the rescue work, if it had to be undertaken at all, had to be carried on as quickly as possible. After a mine was exploded, the mining system in its vicinity was carefully examined for carbon monoxide by testing with canaries or mice.

In addition to mine rescue work, other mining operations were carried out by men wearing the apparatus, such as restoring the ventilation, examination of the mine system after hostile explosions, and in one case charging and tamping a mine. In this latter instance it was absolutely necessary to charge a mine for offensive purposes when the whole of the mining galleries were full of carbon monoxide. A squad of men was organised, and worked in shifts of two hours. A charge of some 5000 lb. of explosives was placed in position, the mine tamped and successfully exploded.

The arduous nature of the work of charging and tamping a mine has already been referred to, and it can well be imagined how much more arduous the operation was when the work had to be done by men wearing a cumbersome apparatus in a deadly atmosphere.

The whole rescue organisation attained a very high state of efficiency, and constant practice enabled the rescue men to perform exceptionally arduous and trying work. The trench rescue stations were established in specially constructed dug-outs, where all rescue apparatus and accessories were stored. The apparatus was constantly being examined and tested by

a specially appointed man, and generally the sets of 'Proto' apparatus were changed about every 10 or 14 days for freshly charged sets from the mine rescue schools, in order to obviate any defect due to leakage and the effect of storage in damp dugouts. The enemy employed 'Draeger' rescue apparatus for his rescue work.

Occasionally the rescue squads were requisitioned for work in dugouts which had been blown in by heavy Minenwerfer shells, such explosions in a confined space giving off large volumes of carbon monoxide. In some cases of fires in dugouts and subways the apparatus was effectively employed.

The work of the rescue squads deserves special commendation and affords a striking illustration of the possibility of men being able to work in self-contained breathing apparatus under almost impossible conditions—provided such men are physically fit, properly trained, and that the strictest discipline is observed in connection with the training and during the actual carrying out of rescue operations. By insisting that the rules laid down for rescue work were always followed absolutely to the letter the casualties amongst rescue squads were very few, and when they did happen were always due to neglect on the part of the wearer.

The enemy mining system and methods of mining were much the same as ours. The size of their galleries and their methods of timbering, ventilation, drainage, etc., were practically identical. The methods of working were different because the enemy miner did not seem to possess the same energy and courage as the British miner—for instance, it was well known that after a mine explosion the enemy miners never entered their mining system until a period of twenty-four hours had elapsed, and the fact that the British miners, who commenced their operations under serious disabilities, were able, within a comparatively short time, to drive the enemy back and establish a very complete defensive mining

system is a proof of their superiority over the enemy. The extensive operations at Messines, for example, were successfully completed without giving rise to any suspicion that serious mining projects were in progress.

Before our defensive mining system had been more or less established, and in fact during the work of making the system, it was necessary to find out as much as possible what the enemy operations were. To some extent this was done by surface observations from observation posts and from the trenches through periscopes; but except for ascertaining the position of the mine entrances, such observations gave but little indication of the position of enemy galleries. The only means of finding out where galleries were being made was by listening. Originally this listening was performed by a miner, who sat all day in the face of a gallery listening for every sound. As experience was gained in mining it became necessary to devise some means whereby listening methods became more effective. Several appliances were in use, but the most general was a kind of stethoscope, which was technically called a geophone. This consisted of a small disc-like box about 4 inches in diameter containing mercury, to which was attached a length of tubing terminating in an earpiece which could be applied to both ears. By the use of this instrument all sounds were very accentuated, and it was possible to pick up sounds which were inaudible to the naked ear.

In connection with the mine rescue schools, experimental mines were constructed in various kinds of soil which afforded practice to the miners in direct listening and in the use of this instrument. They soon became very expert, and could infallibly detect any sounds of mining. Later, other experiments were evolved, whereby it was possible, not only to detect sounds inaudible to the naked ear, but also to ascertain the direction and the distance of the point where working was

in operation from the gallery where the listener was situated. Finally, listening stations were set up, detectors fixed in every listening post, and connected to the listening station on the principle of a telephone exchange. The listener sat in the station with a listening board in front of him and a headpiece fixed over his ears. By switching on to the several posts in turn, he could, without moving from the listening station, keep a very close observation on every listening post. Previous to this arrangement, the system of listening involved the constant presence of a trained listener in every post. Of course, if a mine exploded in the vicinity of these posts, the listener's chance of getting away was very remote indeed. This method of centralising the listening saved a large number of men, as one man could do what might previously have been done by fifteen or twenty. Even with the system of listening stations, direct listening had, to some extent, to be employed, as there was always a danger that the wires might be damaged, and it was necessary to test each post at frequent intervals. The listener patrolled each post several times during the shift, and had a system of tapping which enabled the listener at the central station to know whether all the appliances were in working order. The ordinary direct listener's duty, before the inauguration of special listening appliances, was very trying. It is almost impossible to imagine what it is like to sit down all alone at the end of a gallery well away under 'No man's land' and possibly within very close proximity of enemy mines. Very often a man would be physically uncomfortable, owing to water on the floor of the listening posts, perhaps percolating through the roof, besides which there was the mental discomfort of never knowing when he might be blown up. It was particularly nerve-racking, and the work could only be done effectively by a man who was absolutely devoid of any sense of imagination. Listeners had to be very carefully

selected, and it depended entirely upon a man's temperament as to whether he would be an efficient listener. A man with an imaginative temperament was quite impossible, as he was constantly reporting sounds of hostile mining when possibly he heard nothing more than his own heart beating. It was surprising how happy some men were at this work, provided they did not allow themselves to think of the possibilities of the position they were in. The writer has seen men in listening posts apparently feeling quite comfortable when enemy mining was so near that vibration of the face of the gallery, due to picking, was distinctly apparent. Listeners always considered themselves to be quite safe when they could hear the enemy working. It was only when they heard nothing, after perhaps a period of continuous working, that they really became alarmed, as then they had no notion of what was going on in the enemy mining system.

When the listener heard sounds of enemy working, he would immediately report to the officer in charge. It was then the officer's duty to satisfy himself that the report was correct and if possible to form some definite opinion as to what was happening, and if necessary to charge a counter-mine in the nearest available gallery to the post where enemy work was in progress. The verification of the listener's report by the officer frequently involved lying alone in the gallery for several hours with ears glued to the geophone.

There are innumerable instances where the effective listening methods employed have been the means of counteracting the activities of the enemy and saving our own lines from being blown up. It used to be an interesting experience to place a listening detector in a charged mine, connect this back to the fire point and to listen to the enemy miners working away unsuspectingly within a few minutes of firing. This used to be a source of great joy to the

officer whose duty it was to press the plunger of the exploder.

In the course of mining operations cases of intrusion into enemy galleries were fairly frequent, and there are many cases known where hand-to-hand fighting has taken place between the British and German miners underground. The following is one instance of this kind. An attacking gallery was being driven out in a district where it was well known that the enemy was actively mining. Work proceeded very carefully and quietly, when the miner at the face suddenly found that his pick met with no resistance and felt a current of air. The officer in charge was immediately sent for, and upon examination found that an enemy gallery had been struck, and on pushing his hand through the hole he could feel the timbering and various cables fixed at the side of the enemy gallery. The cables were immediately cut, and the officer sat down to consider the situation. After consultation with another officer, it was decided to listen for a period of twelve hours, during which period both officers with revolvers ready took turn and turn about in the face of the gallery, the plan being that if any enemy miner passed he should be fired at and the gallery immediately broken into. Meanwhile mobile charges were prepared, consisting of a box of ammonal with a mechanical firing device attached to a small length of time fuse. No sound was heard during the twelve hours, and it was decided to break into the gallery. It was found that the enemy gallery had been struck into near its face, where an electrical sound detector was discovered, to which the cables previously cut were connected. The exploring party of two officers and two N.C.O.'s advanced along the gallery for a distance of about 250 feet, where a fall of roof was met with, behind which enemy miners were at work clearing the fall. It was decided to explode the charges; the time fuse was set going

and the officers retreated back into their own gallery and awaited results. The charges exploded, but the curious thing was that, within about three minutes after the explosion, another charge exploded which evidently must have been an enemy mobile charge, and no doubt the men working behind the fall must have been enemy miners engaged in laying this charge. Within about half an hour the officers again entered the gallery in rescue apparatus, restored the ventilation, and set about blocking up the gallery with bags of earth, a listening detector being left in the tamping. About 200 feet of enemy gallery was therefore captured. As it was deemed inexpedient to fire a mine at this period, it was decided to do nothing but carry out careful listening. This was done for about a fortnight. Sounds of enemy working were continuously heard, but the location of the sounds could not be determined. However, the enemy must have worked from another point, and one day struck into our gallery with the intention of cutting us off from the captured part. An officer was listening some distance away, with the aid of an electrical listening apparatus (the connecting wires of which passed through the gallery which had been broken into by the enemy), when suddenly all sound ceased, and he at once concluded that the enemy had broken into our gallery and had cut the wires connecting with the listening detector. He promptly advanced to investigate, revolver in hand, and was fired at by an enemy miner. While shots were being exchanged, the enemy fired the fuse of a small charge and retreated. In a few moments the charge exploded and filled the gallery with carbon monoxide. The officer was gassed, but recovered; but another officer whilst making further investigations was killed by the carbon monoxide. The enemy had now more than recovered his gallery, and some action had to be taken immediately to prevent his making good the advantage he had gained, which he might

have done by charging and exploding a mine and thus destroying part of the British mining system at this point. There was no gallery near enough which could be used for countermining. The situation was rectified by a daring operation carried out just after daybreak by the commanding officer of the company and a small party of miners, who by dint of very strenuous digging drove a sharply inclined gallery from a point out in the open in 'No man's land' and over the supposed position of the enemy gallery. This was charged with 500 lb. of explosive and fired within a few hours. The operation resulted in a complete recovery of the original situation, and effectively stopped further mining activity by the enemy. It was a desperate, but eminently successful, undertaking.

Another and different example of intrusion occurred in a long offensive gallery under the enemy lines. While work was going on in the face of this gallery a sudden inrush of water occurred, evidently from abandoned enemy workings. An officer, a N.C.O. and three men were near the face when the water broke in. The gallery was being driven at a slight rise. The inrush of water carried away and drowned the three men, the officer was hurled against some timber and was injured, and when the inrush of water ceased, the officer and the N.C.O. were left high and dry in the face, with their retreat cut off, the inrush of water having filled the gallery back towards the shaft in the British front line. The position was an extremely serious one, and the prospects of release were very remote. The officer and N.C.O. decided to investigate the hole through which the water came, and they found themselves at the bottom of a shaft evidently leading up to the enemy trench. They waited for some hours, thinking that possibly there was some hope of the water being pumped out, but were forced to abandon any further thought of this. Meanwhile, as they were getting very cold and miserable, they decided that their only

chance lay in climbing the enemy shaft, with every possibility of immediate discovery, and attempting to make their way back to the British lines over 'No man's land.' By extraordinary good luck, they got back safely to their own trenches. Similar incidents, of which the foregoing are typical examples, were of common occurrence.

Exact records of all mining operations were kept. All mining galleries were carefully surveyed, and very complete plans of the whole mining system prepared and kept up to date weekly. With the help of aeroplane photographs of the trench systems, all enemy trenches and the position of suspected mine entrances were marked on the mining maps, as also were the positions of all craters caused by mine explosions. To some degree the positions of mine entrances and craters gave a general indication of the enemy mining system. It was impossible to mark the position and extent of the enemy galleries on the mining plans, and this unknown factor was the subject of constant curiosity and conjecture on the part of mining officers. In some cases, enemy galleries were examined and surveyed by effecting an entrance from the enemy trenches at night, under cover of a strong raiding company of Infantry, who, after driving the enemy out, held the trenches for an hour or two while the mines were being examined. After examination, the galleries were damaged as much as possible within the short time available by exploding such charges of explosive as could be conveniently carried by the mining party responsible for the examination and survey.

A very complete geological survey was made all along the line of trenches. By means of bore-holes, sections were obtained which gave exact information as to the parts of the lines where the ground was favourable to mining operations. In some localities the ground was water-logged to within a

few feet of the surface, and in others the general water-logged level might be 15 or 20 feet below the surface. The position of the water level was the deciding factor in fixing the depth of the galleries. In the chalk districts the galleries were sometimes situated at a very considerable depth below the surface.

In addition to the special work of mining already described, Tunnelling Companies were employed in many other operations when the period of extreme mining activity ceased. By this time they had developed into very efficient and well-trained fighting units, and whenever there was any attack, detachments usually went forward with the first wave of the Infantry to carry out demolition work and to examine for concealed mines and traps. During the enemy attack in 1918, when the Allied position was very critical, the miners took their part in the line with the Infantry, and it was partly due to the stubborn resistance of the 251st Tunnelling Company at Givenchy that the enemy failed to develop his advance in the Battle of the Lys. This company had been for three years in this part of the line and knew every inch of it. They had established here very elaborate mined dugouts about 40 feet underground and capable of accommodating a battalion of Infantry. Had it not been for the existence of these dugouts, it would have been impossible for any troops to have lived through the terrific bombardment which was directed against this part of the line. The entrances to the dugouts were constructed of reinforced concrete, which withstood this severe bombardment and made it possible for the garrison in the dugouts to come out and put up a fight after the enemy's artillery barrage had been raised.

All the older parts of the line which had been stationary for several years were honeycombed with underground dugout systems and subways. In some localities these subways were miles in length and sufficiently large to enable troops to

pass through them easily and safely. They were lit by electric light and drained by electric pumps, and afforded sufficient accommodation to whole battalions, who were thus enabled to live underground in comparative comfort and safe from the heaviest bombardment.

When the retirement of the enemy began in the middle of 1918 the miners were employed to make examinations of all houses, dugouts, shelters and all places which had been occupied by the enemy, for hidden mines, demolition charges and booby traps.

It would be a lengthy task to describe all the ingenious devices which the enemy used. It was almost impossible to enter any dugout or building without discovering some trap calculated to destroy the unwary. Anything attractive in appearance was exceptionally dangerous to a man who attempted to take it as a souvenir, as it was probably attached to an explosive charge of some kind, which would explode when the coveted souvenir was lifted. The miners became very expert in detecting booby traps, and very few escaped their notice.

About as unpleasant a task as ever the miners had to perform consisted of the search for and discovery of delay action mines after an enemy retirement. These mines were very ingenious, and consisted of a heavy charge in which were placed delay action fuses, so constructed as to explode within one or two months after laying. The striker attached to a delay action fuse was prevented from operating by means of a thin wire encased in a metal receptacle containing acid. In course of time the acid corroded the wire until it became too weak to withstand the spring which operated the striking arrangement. The thickness of the wire and the strength of the acid used had been carefully worked out, so the date upon which the mines were to explode was calculated to within a day, more or less.

When the Armistice was signed, the German envoys produced plans showing the position of all the delay action mines which had been laid. It was the unenviable work of Tunnelling Companies to unearth these mines, a large number of which were due to explode. The plans were on a small scale and did not indicate the exact points. It was therefore necessary to dig in an area of several square yards before the charges were discovered. Several serious casualties occurred. Subsequently German mining officers were requisitioned in accordance with the terms of the Armistice to show the position of these mines. Later the work was transferred, and rightly so, to German prisoners of war, and in one or two instances complete working parties were blown up.

The activities of the miner outside his own special sphere of mining warfare were by no means confined to the removal of booby traps and concealed mines. The authorities soon recognised that the personnel of Tunnelling Companies, by reason of its skilled character, was adaptable for practically any type of field engineering, and when mining activity abated Tunnelling Companies were employed in bridge building, road construction, the erection of reinforced concrete pill-boxes and machine-gun emplacements, and all types of field engineering works required in the advanced forward zones. When the town of Bethune was set on fire by enemy incendiary shells, a Tunnelling Company was detailed to combat the fire and save the town from complete destruction.

In the early days of the war, when perforce both officers and men were shipped overseas in a very raw state of military efficiency, it was a very motley collection of men that used to be seen marching up to the trenches. However, it was but a short time before they established their reputations, and the extensive knowledge they gained by reason of their occupation of certain parts of the front lines for long periods proved to

be of inestimable value to new divisions coming into the line for the first time. Their reputation was further enhanced by being constantly called upon to take part in active fighting with the Infantry, and companies were being continually commended by the higher commands.

In concluding this somewhat inadequate narrative of the work of the miner in the war, the writer would like to quote the following order, issued by Lord Haig upon the termination of hostilities:

Special Order of the Day. By Field-Marshal Lord Douglas Haig, K.T., G.C.B. G.C.V.O., K.C.I.E., Commander-in-Chief, British Armies in France.

A large number of men are now being withdrawn from Tunnelling Companies for urgent work at home.

Before they leave the country I wish to convey to the Controllers of Mines and to all ranks of Tunnelling Companies, both Imperial and Overseas, my very keen appreciation of the fine work that has been done by the Tunnelling Companies throughout the last four years.

At their own special work, Mine Warfare, they have demonstrated their complete superiority over the Germans, and whether in the patient defensive mining, in the magnificent success at Messines, or in the preparation for the offensives of the Somme, Arras and Ypres, they have shown the highest qualities both as Military Engineers and as fighting troops.

Their work in the very dangerous task of removing enemy traps and delay action charges, on subways, dugouts, bridging, roads, and the variety of other services on which they have been engaged has been on a level with their work in the mines.

They have earned the thanks of the whole Army for their contribution to the defeat of the enemy. Their fighting spirit

and technical efficiency has enhanced the reputation of the whole Corps of Royal Engineers, and of the Engineers of the Overseas Forces.

I should like to include in the appreciation the work done by the Army Mine Schools and by the Australian Electrical and Mechanical Mining and Boring Company.

D. Haig, F.M.,
*Commander-in-Chief,*
*British Armies in France.*

General Headquarters,
*December* 4, 1918.

Captain Ivor Evans' paper was illustrated with lantern slides, some of which were explained by Major Ball.

Captain Evans mentioned that one Tunnelling Company alone was awarded—2 D.S.O.s, 14 M.C.s, 9 D.C.M.s, 46 M.M.s, 1 Croix de Guerre, and 1 Médaille Militaire.

A cordial vote of thanks was passed to Captain Evans and Major Ball, and the discussion was adjourned.

# NOTES ON OUTBURST OF GAS AND DUST AT THE PONTHENRY COLLIERY.

By George Roblings.

# NOTES ON OUTBURST OF GAS AND DUST AT THE PONTHENRY COLLIERY.

By George Roblings.

In forwarding these notes for insertion in the 'Proceedings' the writer has for his aim the placing on record of an occurrence which is, fortunately, comparatively rare.

The Pumpquart Seam of the Gwendraeth Valley, equivalent to the Lower Pumpquart of the Ammanford District, has a normal section as shown in Fig. 1, but it very often departs from the normal both in section and in the character of the coal, this variation sometimes taking place within very small areas. Coal requiring the use of explosives would perhaps within a few feet be succeeded by what may be called fine Duff, or vice versa, as shown in Fig. 3, which is a section along AB in Fig. 2.

The main slant was being driven nearly to the full dip of the measures, which was at this point as low as 7 inches per yard. The section along the lowest 50 yards of the slant is shown in Fig. 5; and at B, the point at which the heading was turned and driven in along the level course westward, and known as the 21 West heading, there was no bottom coal.

At this point there is approximately 900 feet of cover. A section along this heading, which was 22 yards in bye from the slant at the time of the outburst, is shown on Fig. 3. It will be noticed that the lower coal is either absent or undergoing considerable variation in thickness, and is very friable, yielding nothing above peas, and even those could be crushed between

the fingers. The top coal continued strong and consistent in thickness throughout.

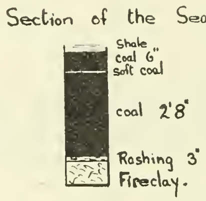
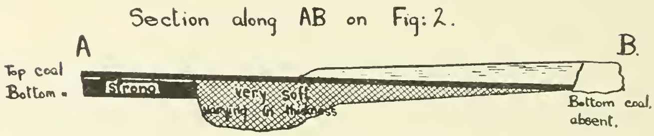



Fig: 1

Fig: 3.



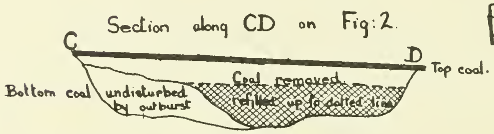
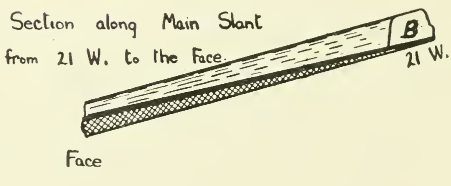




Fig: 4

Fig: 5




This heading was being driven for the purpose of exploring, as the extent of the nipout was not known.

About noon on February 27 last, while one of the workmen was sounding the coal, he received for reply several sharp reports like the exhaust of a motor-car, and then ran away. By the time they reached the parting, one of them was blown

across the slant by the force of the current. The men below, in the face of the slant, having heard the reports, also took steps to escape, and while passing the heading experienced great difficulty owing to the gas and dust, which, as they say, resembled the outlet of a winnowing machine of considerable capacity.

The reports continued for some appreciable time to increase in intensity, and gave the impression to men some distance up the slant of two separate series of outbursts, the last one being by far the more violent, the sound being described as similar to the whistling of a gale through trees.

Every lamp in the seam (148 in number) was extinguished, as well as two in another seam near the Fan Drift, where the return air from the other slant had been momentarily insufficient to dilute this fire-damp, while it was driven for 500 yards up the slant against the intake air current to the point marked on Fig. 7.

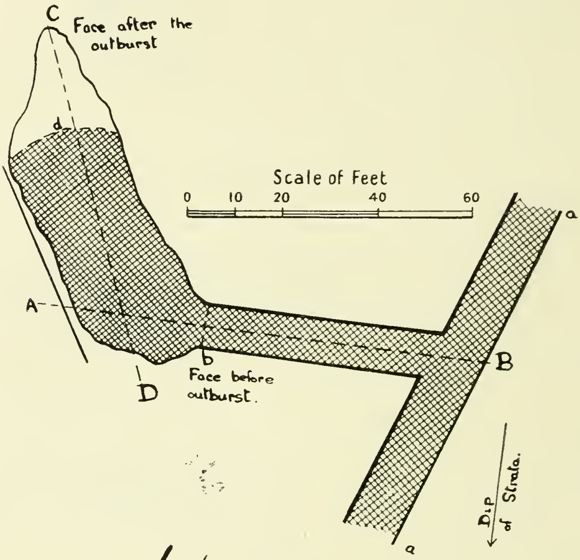
Exploration work was immediately commenced, and all the men brought out, except one, who was found kneeling at the side, 60 yards from the parting of the 21 West heading, unfortunately having been suffocated by the gas and dust. See Fig. 7.

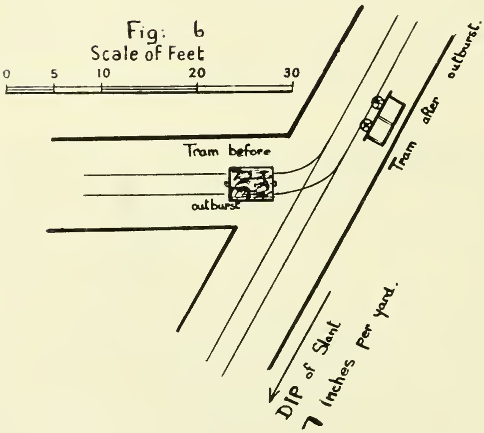
Several men who had been behind him were also rendered unconscious; but, owing to the fact that they fell into the middle of the road, were able to get such oxygen as would be present under the gas, and by coming in contact with a small stream of water which ran down the middle of the road were revived and restored to consciousness.

The gas presented an impenetrable barrier, for some hours, to any flame safety-lamps at the point on the slant which the gas reached, and all exploring work was undertaken by the aid of electric lamps, and progress was made only along the floor.

When an attempt was made to reach the 21 West heading to ascertain the conditions existent there, a barrier of small

Fig. 2.—Plan of the 21 West Heading and Portion of the Slant.
Part shaded from *a* to *b*, roads filled with small coal.
" " " *b* to *d*, coal removed and partly refilled.




coal and fine dust was met with 10 yards above the parting, and filling the slant to within 10 inches of the roof. It was found that 23 yards of the slant and 22 yards of the heading

were similarly filled with this fine coal. See shaded portion between *aa, b* on Fig. 2.

Palpable dust was found for nearly 100 yards up the slant of an appreciable depth in some places.

The appearance of the surface of the fine-coal heap gave every indication of having been swept by a powerful current.

It was subsequently found that a further considerable quantity of coal had been displaced inside the then position of the face of the heading, partly occupying the space cleared of the coal found on the roads. The whole area affected is shown on Fig. 2, with its accompanying sections Figs. 3 and 4.

Prior to the outburst, a tram weighing 29 cwt. gross was standing on the heading at the parting awaiting to be hauled up, but when the coal was being cleared this was found tumbled on to the opposite side of the slant, at a point about 3 yards to the rise, as shown on Fig. 6.

Every pair of timbers on the heading, together with the framing timbers, were blown out, and were found down the slant, having probably rolled down, some of them having previously been carried for a distance of 20 yards along the heading.

The quantity of small coal filled from the roads was 170 tons, and a further 110 tons which had been removed or otherwise disturbed inside the original face of the heading.

The barometer about that time suffered but a very slight depression, and in the writer's opinion is more a coincidence than a contributing cause, owing to the fact that the coal which offered resistance to the gases was being worked away, and that when it was sufficiently weakened it gave way.

Some anxiety was subsequently caused by the heat which was noticed in the heap of loose coal. A thermometer was inserted and kept moving forward about 3 feet ahead of the

workmen, and the readings varied from 94° to 138° F. The temperature was found to be greater at the bottom of the heap.

In the matter of obtaining some slight idea of the pressures

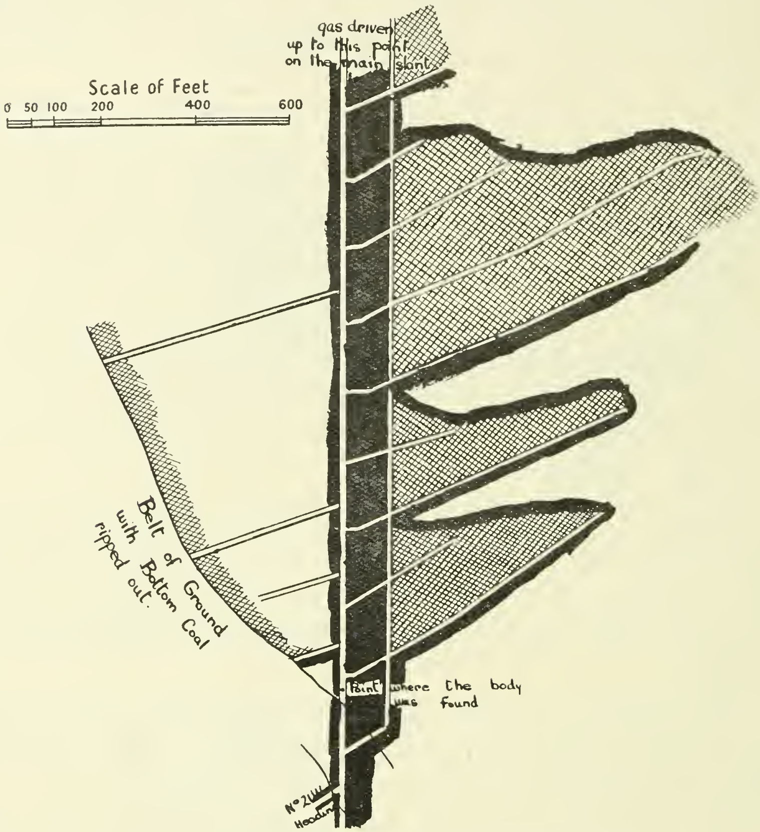



Fig. 7.—Plan of Portion of the Pumpquart Workings.

involved, the tumbled tram was the only means by which any suggestion could be obtained. A tram similarly loaded was placed on the heading near the parting, and a Salter's Spring Balance was placed between the tram and the rope, and the whole drawn slowly out of the heading and up the slant, the rate being about one mile per hour. The pull

registered was 616 lb., being equivalent to 88 lb. per square foot, blowing directly on to the end of the tram.

Taking the formula to find the pressure produced by falling bodies, and assuming the current was entirely composed of fire-damp, the velocity necessary to produce the above pressure would have been 21,787 feet per minute.

There is no doubt but that this figure is excessive, inasmuch as the current carried with it considerable quantities of fine coal, thereby materially increasing its density, and capable therefore of exerting the given pressure at a considerably lower velocity. Regard should, however, be had to the fact that the tram had not during the whole of the time its end directly in line with the current, owing to turning the curve, and consequently had but the component part of the force to propel it along.

With reference to the tumbling, this may be due to one of two causes, or both to some extent combined :—

(*a*) The speed of the tram around the curve.

(*b*) The pressure of the current against the side of the tram as it changed its direction from the heading to the slant.

It is difficult to gauge the pressure from the timbers that were carried out, as one does not know either the velocity or the manner in which they were propelled.

Sufficient has, I think, been said to show that the velocity was considerable, and that it must have continued for some appreciable time, and consequently that a very considerable quantity of gas was given off.

In investigating the cause of such an outburst several points arise, some having a direct bearing and others indirect, but of interest, nevertheless.

In the writer's opinion the first thing was to find where the gas came from. It can be readily established that the

gas was occluded in the coal, and when it is remembered that a greater volume is occluded in anthracite coal than in any other, it can be readily understood that there is more to be released, if there is insufficient cohesive force in the particles of coal to retain it.

In some tests carried out by Mr. C. A. Seyler it was found that 450 c.cm. of gas (92 per cent. of which is fire-damp) and 6·43 per cent. of carbon dioxide was obtained from 100 grams of strong coal, while, given a similar weight of soft coal, only 95 c.cm. of gas was extracted, of which nearly 63 per cent. was carbon dioxide, and only about 12 per cent. of fire-damp.

It is evident that a considerable quantity of fire-damp had been lost, if we assume that there was at least as much originally occluded in the soft coal as was found in the strong coal; but when consideration is given to the tram and the timber, a far greater quantity of gas has to be accounted for than by the release of a quantity which has been shown to be occluded in the strong coal.

In considering this matter one is impressed with the porous nature of these friable coals, and that it is safe to assume that these pores were also charged probably at high pressures with fire-damp, in order to account for the enormous quantity of gas released.

It has been found that whenever the friable coals have been met with more gas has been given off than in the strong coal, and that less trouble is experienced from this cause when the coal has been worked by wide work than when narrow roads have been resorted to.

It is pertinent, therefore, to consider whether any relationship exists between the pressure of the gas and the friability of the coal, but the writer does not feel competent to offer an opinion, although he thinks it is more than mere coincidence.

Around the area from which the outburst emanated the

coal remaining *in situ* gives the appearance of having been crumbled, and provides evidence of intense crushing: the fact, however, remains that no such evidence exists in the top coal, which has consistently maintained its strong character and uniform thickness over the whole area, thus tending to suggest that any changes which had been brought about had been so prior to the deposition of the top coal.

While the floor is very uneven, as shown by the sketches, the roof is, on the other hand, of a uniform character both as regards dip and quality throughout, more or less confirming the theory that the changes must previously have taken place, although the evidence of intense crushing appears to be somewhat inconsistent with this view, unless the latter was due to intense internal pressure owing to a large quantity of occluded gas, more or less at a high pressure.

It has been previously mentioned that the amount of occluded gases is far greater in anthracite coal than in any other class, and this leads to the question as to whether the difference in the various classes of coal may be due to whatever action has caused this difference in the occluded gases.

The writer believes that an investigation along this line may possibly solve the question, and lead us to the true cause of the formation of anthracite; and he is inclined to draw a parallel with the action of bacteria in the treatment of sewage, where in the process large quantities of inflammable gas, probably marsh gas, are given off at a stage where the solid organic matter is more or less liquefied by their action, and therefore destroying the original structure of the organic matter involved.

The writer is neither a chemist nor a bacteriologist, and perhaps, therefore, may be forgiven for venturing to put forward this idea, which, however, may extract an answer from those members well versed in these two branches of

science, and which may help to solve this difficult problem of finding the origin of anthracite.

The discussion upon these few notes, the writer hopes, will assist in revealing the causes of several apparently obscure occurrences, and therein lies the one aim of the writer in communicating these notes, and presuming to enter them in the same Proceedings as the high-class scientific contributions which have recently adorned them.

## The Discussion.

**The President.** The PRESIDENT said the subject of Mr. Roblings' paper was important, and merited the careful consideration of their best geologists and chemists with a view to ascertain the cause of this outburst of gas and dust. There were not many similar occurrences on record. A few papers had been read to the Manchester Geological Society describing outbursts in the Lancashire area, and there had been several large outbursts of gas in the South Wales steam coal area, but there was no dust outburst as well. There had, however, been one or two other cases in the anthracite area. With regard to the eastern part of the coalfield, Mr. E. M. Hann, ex-President of the Institute, read a paper on an outburst of gas at the Aberaman Colliery some years ago; and sixteen or seventeen years ago there was a serious outburst of gas in one of the lower seams at Nixon's Navigation Colliery, Merthyr Vale. In the latter case, the gas put out all the lights practically from the place of origin to the upcast shaft. He himself investigated the occurrence at Merthyr Vale, where they were not able to get to the seat of the outburst for three weeks afterwards. With regard to the subject of the paper, it was fortunate—so far as the gas outburst was concerned—that the chief method of lighting at Ponthenry Colliery was by oil safety lamps and not by electric lamps. The collier had become particularly partial to the electric lamp, which in many respects was a

superior lamp. Where it was generally used in the mine, the safest plan was to have oil safety lamps placed here and there along the face so as to give early indication of the presence of gas and the volume of it. At Ponthenry 148 oil safety lamps were extinguished in the affected seam. What would have happened if they had been electric lamps was not difficult to conjecture. The men would probably have continued to work after the gas outburst had occurred, and become overwhelmed by the poison. It was possible, if the man who lost his life had had an electric lamp, he might have found his way out, or if there had been an electric lamp or two at the bottom end of the drift. Then there was the case of the outburst at South Wales Primrose Colliery, at Tareni, some years ago. That was a rather serious outburst of dust as well as gas, by which one man lost his life. He was found buried over his head in very small coal: smothered in it. Another outburst occurred at Tareni, but this was not so difficult as the first. Now, in each case the outburst was near a large disturbance—at Ponthenry and Tareni, the latter being the deepest pit working the Brass vein. He was glad Mr. Roblings had brought this matter to the notice of the Institute, and when discussion upon the paper was resumed at the next meeting he hoped as many managers of anthracite collieries as possible would make the journey to Cardiff on that occasion, to go fully into the points raised. The President.

The discussion was adjourned.

Mr. James Ashworth (Livingstone, Alberta) writes: Mr. James Ashworth.

There are several points of much interest in this paper on 'An Outburst of Gas and Dust at the Ponthenry Colliery,' thus, for instance, the writer would ask Mr. Roblings what theory he advances to account for the bottom part of the seam of anthracite being so soft, and, secondly, whether such soft places have been previously encountered without outbursts of gas and dust?

Mr. James Ashworth.

In one particular coalfield in British Columbia which has attained some notoriety, similar outbursts, but on a much larger scale, have been attributed to local strains and stresses due to faultings of the strata, but at Ponthenry this does not seem to have been the case as the top part of the seam was not crushed.

It would add much to the interest of this paper if analyses of both the hard and the soft parts of the seam were given, also of the gas which was given off during the outburst. In British Columbia samples of the gases given off in the very gassy mines are systematically taken and analysed, with the result that ethane, pentane, and hydrogen have been discovered mixed with the methane.

The writer has for some years tried to find definite proof that the higher hydrocarbon gases exist in the coal-seams in the form of a liquid spirit, and that as this liquid volatilises it pushes off the coal in flake or very fine dust, and so on continuously until the soft part of the seam has exhausted its gaseous contents. This seems to him to be the only way to account for the very considerable length of time occupied by many of these demonstrations of natural forces, and the huge volumes of gas and fine dust thus produced. (Quotations from the work of other theorists will be found in the pamphlet copy of the writer's article on 'Firedamp,' enclosed herewith.)

Another interesting fact is stated by Mr. Roblings, viz., that a high temperature was found in the displaced fine coal dust, which appears to show that very great friction must have accompanied the outburst, in addition to the oxidising effect of the air, and the possibility that static electricity was also created by the friction ?

The cause of the heating effect on this class of coal, which is at all times difficult to ignite, would form an extremely interesting theory.

# PROCEEDINGS.

A Special General Evening Meeting of the Institute was held at the Institution, Cardiff, on Thursday, October 7, 1920, the President, Mr. J. Dyer Lewis, occupying the chair.

## The Late Mr. S. W. Allen.

The President said before entering upon the business of the meeting it was his painful duty to announce the death of Mr. S. W. Allen, who many years ago took an active part in the work of the Institute. Most of the members would recall the geniality of Mr. Allen, with especially pleasant memories of the social side of his character at their excursions and annual dinners. His personal qualities made him popular and esteemed on all hands. He (the President) moved that the Secretary be asked to convey to Mrs. Allen an expression of their sympathy. The President.

Mr. W. D. Wight, in seconding, said while the younger members of the Institute might not be aware of it, Mr. Allen was an enthusiastic and useful member in former years. As the President had indicated, he was most popular for his happy and witty disposition, and those who were privileged to know him over a long series of years deeply regretted his death. Mr. W. D. Wight.

The resolution of condolence with the widow was carried by members rising in silence.

## On the Use of the Cement Gun for Underground Work in Collieries and for Housing Construction.

By A. E. Parker.

The President.

The President said the first subject on the agenda was the paper of Mr. Parker on the Cement Gun and Gunite.

Mr. A. E. Parker.

Mr. A. E. Parker said that, with the permission of the President, he would like before delivering his paper to say how much he appreciated the kindness of the proprietors of the Melingriffith Works for affording facilities for the demonstration that afternoon. When he first mentioned the matter to Mr. Spence Thomas, that gentleman at once promised every assistance, Mr. W. R. Davies, the General Manager, expressed equal willingness, and Mr. Percy Davies, his assistant, had kindly seen to the details of what was necessary for the demonstration.

Mr. Parker then delivered his paper.

# ON THE USE OF THE 'CEMENT GUN' FOR UNDERGROUND WORK IN COLLIERIES AND FOR HOUSING CONSTRUCTION.

By A. E. Parker.

# ON THE USE OF THE 'CEMENT GUN' FOR UNDERGROUND WORK IN COLLIERIES AND FOR HOUSING CONSTRUCTION.

By A. E. Parker.

The machine used for the application of hydrated materials and known as the 'Cement Gun' was introduced about ten years ago after several years experimenting, but it was only comparatively recently that any serious interest had been taken in it in this country. The work done in other countries was so extensive and the results so satisfactory that it would appear to be well worth while considering to what extent the conditions in this country call for its use. As would have been gathered the machine is a mechanical means of applying cement or other hydrated material, and in designing such a machine the important considerations were: the best method of effectively mixing the water with the dry material, how best to get the mixture out of the machine on to the surface to be coated without risk of clogging, and the best means of securing continuous operation. The motive power is compressed air at a pressure of from 35 to 45 lbs. per sq. in., and a supply equal to 150 cubic feet per minute is required. The cement mixture is fed into the machine by hand in a dry state, and is blown from the machine through the hose; when the material, still in a dry state, gets to the nozzle of the hose it meets a fine spray of water, which, being at a slightly higher

pressure than the compressed air, say 55 to 65 lbs., effectively mixes with the dry material.

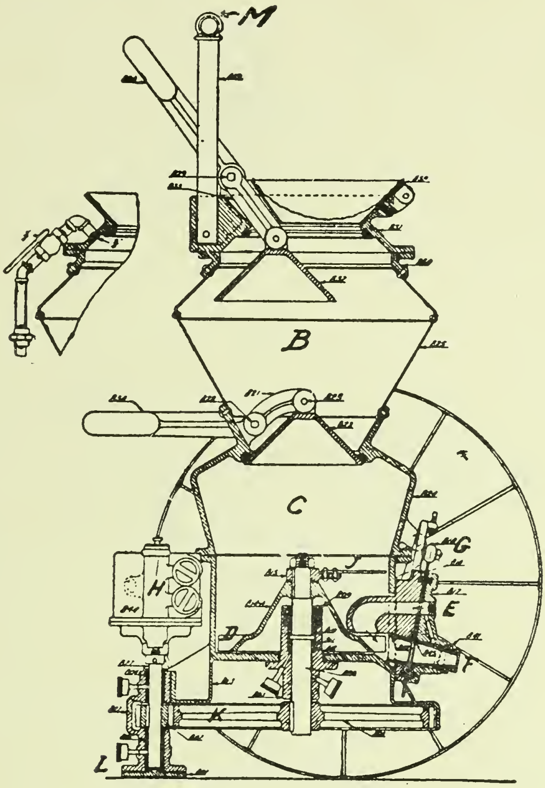
The machine (Fig. 1) consists of two parts, an upper part in the nature of a hopper, with a bell valve at the top, and a lower compartment which has the mechanism for driving the material through pockets in a revolving wheel which gives an intermittent action, and does away with any risk of clogging.

FIG. 1.—'CEMENT GUN' IN OPERATION.

Continuous operation is arranged for by the lower compartment having a bell valve at the top, which is, of course, closed whilst the material is being fed into the upper compartment.

On Figs. 2 and 3 are shown the upper part 'B' and lower part 'C,' at the top of each of which is a bell valve operated by separate hand levers. These two chambers are kept in equilibrium through their respective valve connections with the main pipe. At the bottom of the lower chamber is located the feed wheel 'D,' keyed to a vertical shaft, which in turn is keyed to and driven by a bronze worm gear by means of a worm attached to the horizontal shaft of a small air motor

'H.' As this wheel revolves its individual pockets are brought in front of outlet valve 'F,' and an additional jet of air, on passing through the gooseneck 'E' located immediately above




Sectional Elevation

FIG. 2.

outlet valve 'F,' causes the material in the pockets to be blown out through the latter and thence through the hose to the nozzle or point of application, where the hydration is accomplished.

When the hydrated material is supplied to the surface which has to be coated, there is, of course, a considerable 'pounding' action, which makes for greater density and a

better quality cement than is possible when the material is applied by hand. All the tests which had been made, of which details could be given, went to show that in all respects—

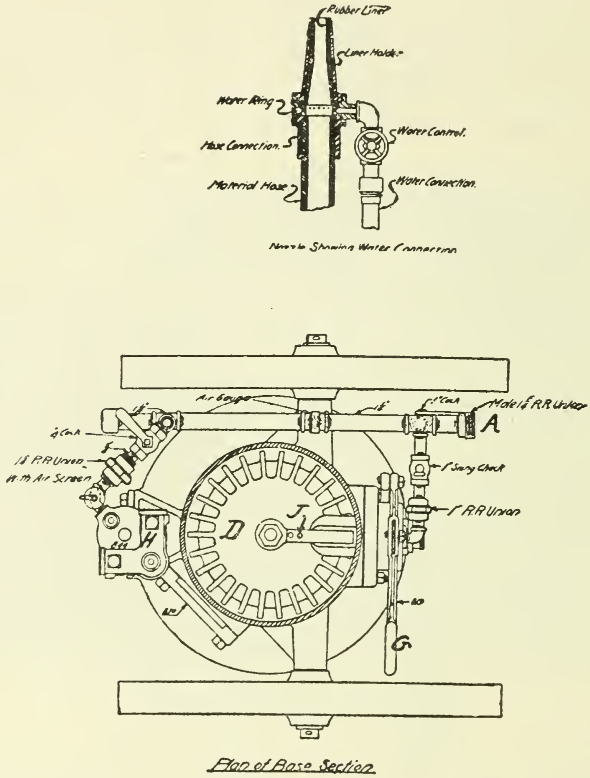



Fig. 3.

compression, adhesion, tension, and so on—the cement, or what is known as 'Gunite,' is greatly superior to cement applied in any other way. The machine, which is 4 ft. 3 ins. high, weighs about 5 cwts., and is quite portable. The various hoses are usually in 50 ft. lengths; the cement hose $1\frac{1}{4}$ in., the air hose also $1\frac{1}{4}$ in., and the water hose $\frac{1}{2}$ in. diameter. The total weight of machine and equipment is approximately 13 cwts.

As to the work which had been or was being done in this

country, he was able, by the kindness of Mr. Edmund L. Hann, of the Powell Duffryn Steam Coal Co. Ltd., to give some details of work done at their Cwmneol Colliery. These particulars had been supplied by Mr. J. A. Price, the agent of the Powell Duffryn Collieries in the Aberdare Valley. On the 13th of last month (September) a roadway inside the pit parting was coated for a length of 33 yards; the average width of the roadway was $10\frac{1}{2}$ ft., and the average height $9\frac{1}{2}$ ft. The sides and roof were hard shale. The roof was coated to an average thickness of $\frac{1}{2}$ in., and the sides 1 in. The area coated was 2931 sq. ft., made up of roof 1039 ft., sides 1743 ft., manholes 149 ft. A three-to-one sand-cement mixture was used, and the quantities were 3 tons of cement and 9 tons of sand (less about 2 tons of sand which rebounded and which was used again). The shift began at 3 P.M., the Gun started at 3.55 P.M. and finished at 9.31 P.M., the total time from start to finish being 5 hours 36 minutes. The Gun was actually working 3 hours 36 minutes, two hours being taken up with examinations, etc. The number of men employed on the machine was four—one at the nozzle, one at the levers, two hauling the mixture and feeding it into the machine. Another four men were employed during the day, screening the sand and the cement, mixing them into the proper proportions, and filling the mixture into the trams. If the time of 3 hours 36 minutes be taken, the average rate at which the cement was applied was 814 sq. ft. per hour.

A Colliery Company in Scotland is using one of these machines for coating roadways underground to prevent roof slacking, and the last report received was to the effect that about 150 yds. had been coated, and that it is the Company's intention to deal with some thousands of yards in a similar way.

The machine is also being used underground in collieries in

Durham and Yorkshire, and he was advised that the results were in every way satisfactory.

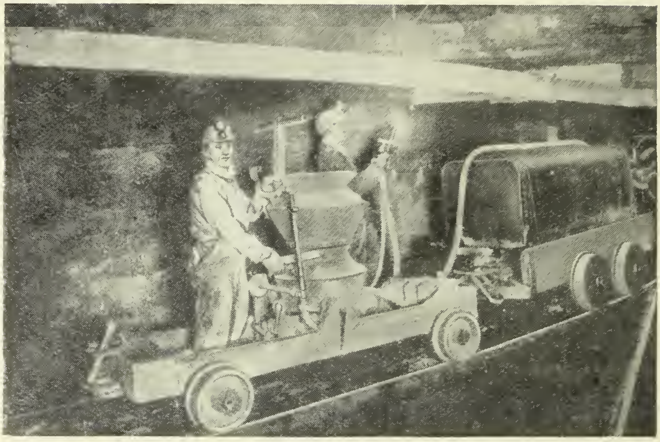


Fig. 4.—'Cement Gun' Outfit in Colliery: Portable Electric-Driven Compressor, Water Tank and 'Cement Gun,' all Mounted on Mine Trucks.

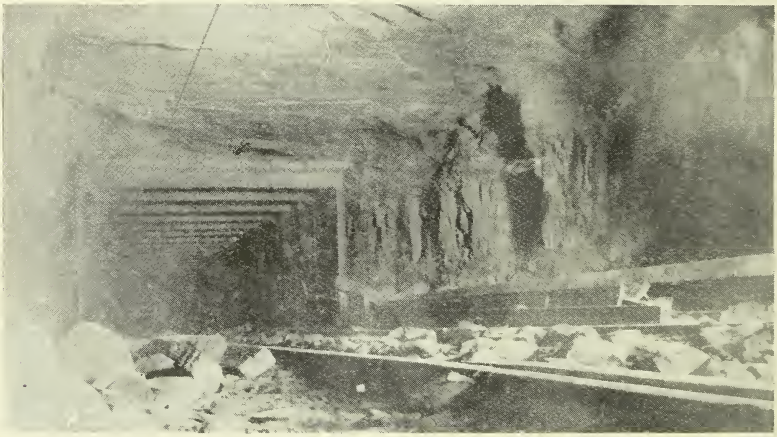


Fig. 5.—Roadway in Colliery Coated with 'Gunite' to Prevent Falls.

Fig. 4 shows clearly a portable plant underground. Fig. 5 is of a roadway after the machine had been at work, whilst Fig. 6 shows reinforcement necessary for the coating of steelwork.

As to the use of the machine in housing construction, a colliery village is being built in Yorkshire where the houses

are being constructed in pairs on steel framing. The steel uprights are at 4 ft. centres, and the reinforcement between uprights is either expanded metal $1\frac{1}{2}$ in. mesh, 12 gauge, or $\frac{3}{8}$ in. Hy-Rib. This reinforcement is wired to the steel uprights through holes previously punched. On the first houses erected a wooden shuttering was used for backing, but to save cost of timber a method has since been adopted of applying a thin coat of cement on the other side of the

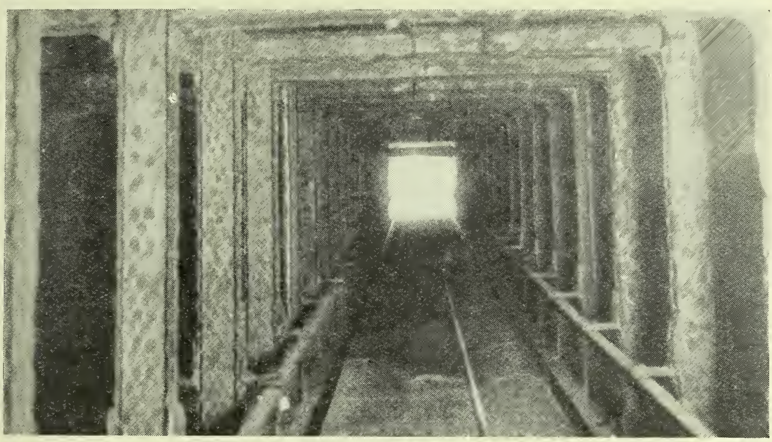


Fig. 6.—Steel Beams in Mine Shaft Wrapped with Reinforcing Ready to be Coated with 'Gunite.'

reinforcement (inside the house) as a backing, which works out far cheaper than wooden shuttering. A coating of about 1 in. thick of 'Gunite' is applied by the machine, which is skimmed to a true surface and allowed to set from seven to ten days before the rough cast finish is applied by the machine. The mixture used on the walls of these houses is $5\frac{1}{2}$ good coarse sand to 1 of cement. The mixture used on the finished coat is a three-to-one sand-cement mixture. I understand that the time taken for coating a pair of houses, including the rough cast finish, may be taken as from 16 to 20 hours, say, 2 to $2\frac{1}{2}$ working days, and that a pair of these houses represent a surface of about 3570 sq. ft.

A Railway Company near London is using two of these machines for dealing with a tunnel which is giving trouble, owing to the eating away of the brickwork. In this case they have put down at the entrance to the tunnel compressors and boiler power for the purpose of operating the 'Cement Gun.' The method of working is for the machine to sand-blast the face of the tunnel and then to apply 'Gunite' to a thickness of about 1 in. In this case they are using a two-to-one sand-cement mixture in the tunnel. A three-to-one mixture was used on the walls outside at the entrance to the tunnel. A length of 40 ft. was sand-blasted in 1½ working days in the tunnel, which is 19 ft. high to the top of the arch, and about 27½ ft. wide. The capacity of the Gun may be taken as six cubic feet, and when working at 40 lbs. air pressure this quantity of cement has been applied to the tunnel in approximately three minutes.

He (Mr. Parker) had since heard that a length of about 400 ft. has been coated in the tunnel, and that the Company purpose coating the entire tunnel, a distance of about 1¼ miles.

Fig. 7 shows the machine at work at the entrance to another railway tunnel.

Underneath a London railway station the machine is being used for sand-blasting and applying cement where the fumes continually eat away the covering of the walls, and as similar work has been carried out elsewhere, with very satisfactory results, showing that cement applied through this machine resists acid and climatic conditions, it is fully expected that good results will be obtained in this case.

He believed that all kinds of preservatives had been used on these arches, but they had not resisted the local conditions for any length of time.

There would appear to be a big field for the use of this

machine in this district, and in coal-mines for such work as preventing roof-slacking, fire-proofing of mine timbers, building of mine stoppages, prevention of air losses, it was particularly useful. For building construction it was evident that a fairly large area to be covered is necessary to justify the use of the machine, but, given sufficient work to do, very much more satisfactory results could be shown than by other means.

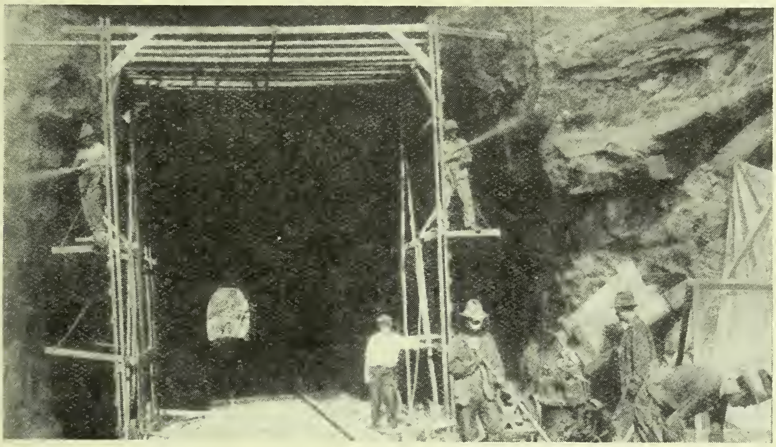


FIG. 7.—LINING A RAILWAY TUNNEL.

For certain purposes in iron and steel works it was also valuable, and for such work as lining railway tunnels, facing reservoirs, coating acid tanks, lining and covering chimney-stacks, repairing sea-walls, etc., the machine had its use.

## The Discussion.

The PRESIDENT, opening the discussion, said it was evident that there was a future for an appliance of the kind described. Unfortunately he found himself unable to go to Melingriffith that afternoon to witness the demonstration, as he had intended, being called away unexpectedly. Those who had anything The President.

The President. to do with practical mining knew very well that the impinging of large volumes of cold air constantly passing along their roadways must of necessity break down the fine shales between their various seams, and a coating of this 'Gunite,' after the roofs and sides had been cleared of stones and loose debris, appeared to afford protection against 'weathering' in the roadways. They knew, too, by experience how difficult it was to stop air leakages by gobbing, and if 'Gunite' proved effective in that respect it would be a most welcome method.

Mr. W. D. Wight. Mr. W. D. Wight said if he understood the matter aright it was claimed for this process that, without any previous preparation beyond taking away the loose materials, the application of half an inch of 'Gunite' preserved their roofs and sides. (Mr. Parker: One inch on the sides, sir.) No doubt it would make the surface look nice and clean, but their difficulties underground in that connection were caused by two happenings. First, they had the natural subsidence of the stratification after taking out the coal underneath, which cracked and broke up the roof above. It could surely not be claimed that an inch or half an inch of 'Gunite' would do anything to support that roof. Then he had always been under the impression that after the heading had been settled to a great extent the variations of temperature had to do with the cracking and breaking of roof. Was it contended that the proposed coating with half an inch of 'Gunite' would prevent the differences of temperature through and around the stratification? He did not ask those questions in any spirit of hostility, but simply to get points cleared up that had arisen in his mind.

Mr. W. O'Connor. Mr. W. O'Connor said he had an opportunity of seeing the 'Cement Gun' at work in the United States some years ago. There, as Mr. Parker had pointed out, the conditions were somewhat different from those prevailing in this country. He

saw the 'Cement Gun' used in the Pittsburg seam, one of the most important in America, being about 500 miles in extent, with a far larger output of coal than any seam in the world. It varied from 5 ft. to 8 ft. in thickness, leaving out local variations, and was covered by a seam of inferior coal about 10 ins. or 1 ft. thick. The mining in this seam—or all that he saw—was done on the pillar and stall method, on narrow working. In driving the roadways they allowed the inferior coal to which he had referred to remain up. While it remained there was no trouble from falls, but when it was down they got a rough shale, from which came a considerable quantity of fine material, and finally he supposed, as the unsupported area increased, there would be serious falls. At some places he saw an attempt had been made to cover this shale with cement and sand, or 'Gunite,' and the coating certainly seemed to have a beneficial effect. Of course, in American mines changes of temperature were very much greater than those to which they were accustomed in this country. He recalled on one occasion he entered a mine at the entrance to which a very large thermometer indicated 88 or more degrees. This was about 7 o'clock in the evening. When he came out of the mine at about 10.30 the thermometer registered two degrees below zero. In those conditions it would be readily understood that the shale would be subjected to 'weathering' of a much more acute type than any in England. Another point was this: they would find on a fairly cold day a bituminous mine as dry as the steam coal of South Wales, and going to the same mine a few days afterwards, with the wind in another direction, they would find everything wet. An instance of this which he specially recalled was the occasion of a visit he paid in company with Mr. George S. Rice, of the American Bureau of Mines, to an experimental mine. Owing to the work being all narrow work, or comparatively so, a larger Mr. W. O'Connor.

Mr. W. O'Connor.

quantity of air taken in at the mouth of the mine was lost than was the case in this country. At about every 20 yards there would be a direct communication between the intake and the return, which, of course, could not be stopped up to anything like airtight. Most of the applications of 'Gunite' which he saw had been made at those places. He had occasion to examine those stoppings both before and after a serious explosion in the mine, and he found that those stoppings on the outer side had prevented air passing in roofs and sides to a noticeable extent. The machine, however, he saw at work in America was a smaller and more handy contrivance than that which was demonstrated with at Melingriffith, but possibly the larger machine was less expensive. With regard to the British conditions and practice, he agreed with Mr. Wight that they could not expect a coating of an inch on the sides and half an inch on the roof to materially withstand the pressure which they experienced underground. He also agreed with Mr. Wight that although this coating might be of some use in modifying the variations of temperature, he did not see how it could be effectual. Nevertheless, the process had its protective value, and to that extent was desirable.

Mr. Evans.

Mr. Evans (Albion Colliery) said in coming to witness the demonstration that afternoon and to listen to the discussion that evening he was prompted by an earnest desire to learn something for the preservation of roadways. As the President was well aware, they had to deal with very bad roads at the colliery with which he was connected. With regard to the application of 'Gunite' they were told that in the first place all the loose material in roofs and sides had to be removed. That would prove a difficult task in his case, because no sooner were loose stones removed than others came fast in their place, and it seemed impossible to get the roof and sides solid. He could see, however, that the coating would be

useful in stopping the air coming through the strata in the case of arches. Some arches had been lately put up at the Albion at crossings between the main intake and the return. There were three sets of roads, and up to now it had been found impossible to stop the air passing through the strata; but a coating of 'Gunite' at the end of the arches might be a very good thing. **Mr. Evans.**

Mr. TREVOR L. MORT said he was rather disappointed with the 'Cement Gun's' volume of work. They had heard the Powell Duffryn figures that evening, but he did not see this progress at the Melingriffith demonstration. He thought, however, the principle was correct. At the same time he agreed with Mr. Wight that a thicker coating was desirable. The machine required a bigger mesh than a quarter of an inch. Some of them had put up horseshoe craters about a yard apart, or at different distances as the case might be, and this 'Gunite' might be useful to apply between the craters outside the timbers to preserve the timbers. In constructing arches underground they had to put up scaffolding to get to the top, and the 'Cement Gun' should be provided with extra pressure to shoot the mixture high enough to save scaffolding. He hoped something of the kind would be done, because everything that helped them in these days was most welcome. **Mr. Trevor L. Mort.**

Mr. E. J. ELFORD (Cardiff City Engineer) said he had come to listen, and hoped to learn from listening. He had no idea he should be called upon to make any remarks. He might say, however, he had been interested in the 'Cement Gun' for a couple of years past, but it was only quite recently he had had the opportunity of seeing it at work and getting detailed information. In regard to housing, he was not quite sure that the method of construction which had been described was altogether satisfactory. As he understood it the building was of steel framework, upon which was stretched a netting that **Mr. E. J. Elford.**

Mr. E. J. Elford.

formed a reinforcement for the 'Gunite,' and the total thickness of the wall was about an inch. Now, something more was required in the walls of a dwelling-house than mere protection from the weather. Walls should be so constructed as to equalise the internal temperature, as far as practicable, at different periods of the year under varying atmospheric conditions. They should also, to some extent, be sound-resisting. He was rather doubtful whether an inch thickness of cement would be satisfactory in those respects. He thought, however, that there was a big field even in housing for the 'Cement Gun.' What he expected from it was that it would enable a less expensive material to be used for the main structure, to which it would afford an effective protection against weather conditions. For instance, concrete breeze blocks, not of high quality, should prove satisfactory if covered with 'Gunite.' In the ordinary way the coating would have to be very carefully applied, occupying considerable time, and even then it might not be a satisfactory job. At the present time, when blocks of that kind were used, it was essential that the walls should be hollow with a continuous cavity, but if cavity blocks could be used, not necessarily forming separate and independent walls, the cost would probably be considerably lessened and the work expedited. There were, of course, many other kinds of buildings to which the objections he had mentioned would not apply, e.g. large structures for industrial and commercial purposes. In these days of scarce material and dear labour he thought there was a big field for that kind of construction. He had listened with interest to the mining engineers who had spoken. He was entirely ignorant of coal-mining, and it was with diffidence he ventured to make a suggestion in regard to the protection of roofs and sides such as had been described. They were probably aware of experiments that were being carried out with the construction

of houses with earth walls. The old mud-house was being resuscitated, with walls protected by pegging on to the outside surfaces, which had become sun-dried and hardened, a light wire-netting, and rendering, either by hand or by means of the cement gun. It seemed to him if something of that kind was done underground and 'Gunite' applied, it would not be necessary to remove so much loose material and some of the difficulties associated with the protection of sides and roofs might be overcome. **Mr. E. J. Elford.**

The PRESIDENT asked what was the life of the 'Cement Gun.' At the bottom of the machine, particularly, there seemed to be a considerable amount of friction where the sand was ground up. **The President.**

Mr. PARKER said that he wished to thank them very much for the kind way in which they had received his paper. He would like to reply to the questions which had been raised at a later date; in the meantime, he thought it well to make a few remarks at once. He had been subject to a time limit, otherwise he could have amplified his remarks considerably. He would like to make clear that the standpoint of those responsible for the 'Cement Gun' and 'Gunite' was not that half an inch, one inch, or any particular thickness of coating was sufficient in all cases. All they said was: 'Here is an opportunity of seeing this machine at work; here is a description of it; we will try to the best of our ability to illustrate its general purpose. Will you be good enough to consider it and see whether it is applicable to your purposes?' **Mr. Parker.**

As regards the South Wales figures he had quoted, he did not know what the Colliery Company referred to intended doing with the machine when they acquired it, and he did not know until a few days before that they had taken records of the work they had done underground. They had been kind enough to allow particulars to be given, and he thought they were very interesting.

Mr. Parker. As to the size of the machine, it only weighed about 5 cwts., and the equipment about another 8 cwts.; the latter, made up of hose, etc., was all detachable, and the outfit was quite portable.

They did not claim for the machine that if there were a shaky roof all they had to do was to apply 'Gunite' and their difficulties would be at an end. That was not the point of view at all. What they suggested in regard to mining was that the machine was a very useful adjunct to a colliery of any considerable size, and that under certain conditions a very considerable saving could be shown by the use of the machine.

As regards the work done by the machine that afternoon, it should not be overlooked that some of the cavities in the wall to which 'Gunite' had been applied were very large; in fact he was advised that one hole took practically the contents of the Gun to fill.

In regard to the construction of the houses to which reference had been made, one inch of 'Gunite' was applied to the steel reinforcement on the outside; he understood that cavity walls were being made with concrete breeze blocks on the inside.

As to the life of the machine, there were one or two wearing parts in the equipment, the rubber linings in the nozzle varied in length of life, and of course the hose through which the 'Gunite' was forced also gave out in time, but the machine itself, in the ordinary way, lasted for years.

With the President's permission he would reserve further comments until he had the notes of the discussion before him.

The President. The PRESIDENT said he would adjourn the discussion to the November meeting of the Institute. Meanwhile, he moved a hearty vote of thanks to Mr. Parker for his paper and demonstration at Melingriffith. (Applause.)

The President. The PRESIDENT said that the next paper for consideration was one by Mr. Ernest Breffit on 'The Imperial Tie Tamper.'

# NOTES ON IMPERIAL TIE TAMPERS.

By Ernest Breffit.

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By Ernest Breffit.

The incentive for the development of the pneumatic tie tamper was to produce a mechanical means of tamping crushed stone and other grades of ballast under railroad ties and thereby relieve the workman of the most arduous duty of track maintenance. In its present state it not only fulfils the best hopes of its inventors, but produces a more uniform quality of work and an easier riding and safer track.

This tie tamper (Fig. 1) is a percussion hammer arranged with two handles and fitted with a tamping bar which is dressed on the face the same as the hand tamping pick or bar.

The weight of the machine itself is about 35 lb., and its weight, including throttle connection and tamping bar, about 43½ lb.; the length of the machine with bar inserted is 46 inches. The tie tamper is operated by compressed air under any pressure of from 60 to 100 lb., but the best results are obtained with an average working pressure of 70 lb., at which pressure the air consumption is 16 cubic feet of free air per minute.

Three different types of tamping bars are used (Fig. 2), according to the grade of ballast being tamped:

Bar 18 inches long with ⅝-inch by 3-inch face for rock ballast 2-inch mesh up.

Bar 18 inches long with ⅞-inch by 3-inch face for rock ballast finer than 2-inch mesh, wash-gravel and slag.

Bar 18 inches long with $1\frac{1}{8}$-inch by 3-inch face for cinders, earth, gravel, sand, or chat ballast.

Where air pressure from existing air power lines is not

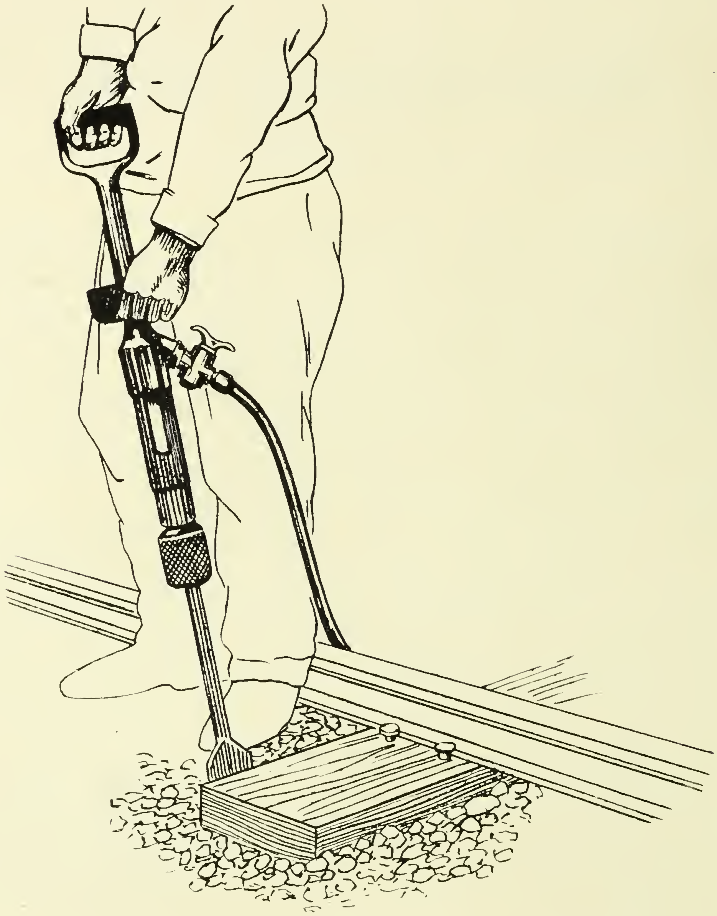

Fig. 1.

obtainable, self-propelled compressor car power plants can be run on the track. These gasoline engine compressor cars are built in two sizes—for two or four tamper capacities. Fig. 3 shows one for operating two tie tampers.

The compressed air is conveyed in $\frac{3}{4}$-inch air hose in 25

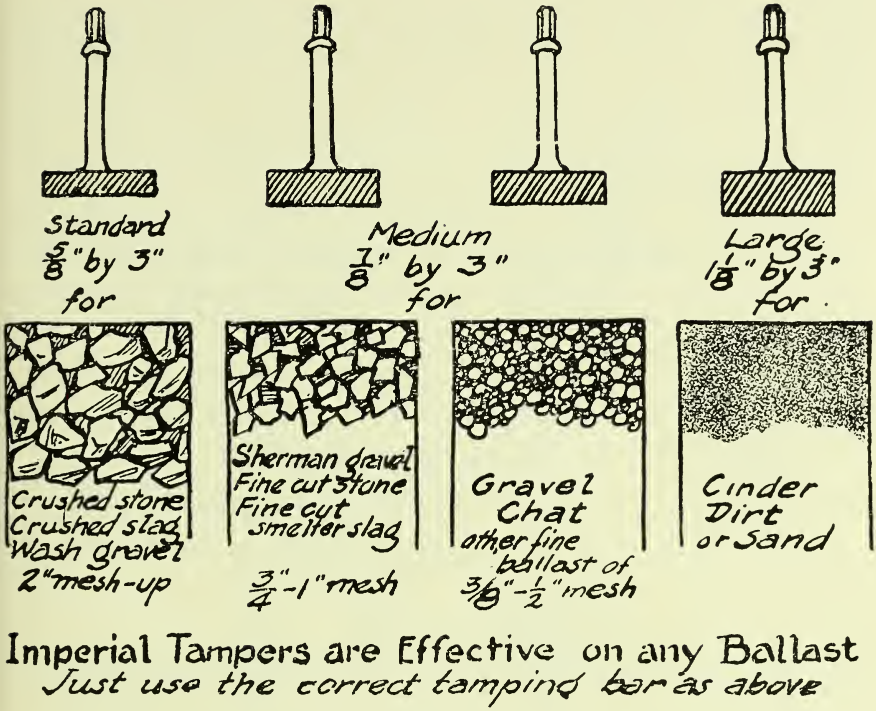
Standard
5/8" by 3"
for
Medium
7/8" by 3"
for
Large
1 1/8" by 3"
for
Crushed stone
Crushed slag
Wash gravel
2" mesh-up
Sherman gravel
Fine cut stone
Fine cut
smelter slag
3/4"-1" mesh
Gravel
Chat
other fine
ballast of
3/8"-1/2" mesh
Cinder
Dirt
or Sand
Imperial Tampers are Effective on any Ballast
Just use the correct tamping bar as above

FIG. 2.

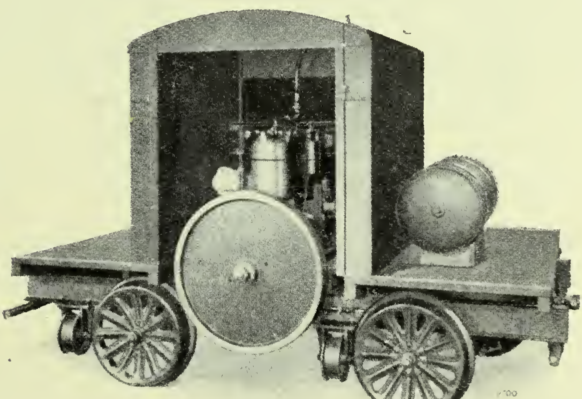

FIG. 3

or 50 feet lengths, joined up by a tee connection to two $12\frac{1}{2}$ feet lengths of $\frac{1}{2}$-inch air hose with suitable connections for attaching to the tampers; a length of 300 feet air hose thus permits the tamping of 600 feet of track (300 feet either way) without moving the car.

The action of the tie tamper differs from the ordinary method of tamping, in that the tamping bar remains in contact with the ballast whilst in operation instead of being lifted up and down as in the case of hand tamping.

The tie tamper is equipped with a retainer for holding the tamping bar in the machine so that it will not drop out when being lifted from one position to another.

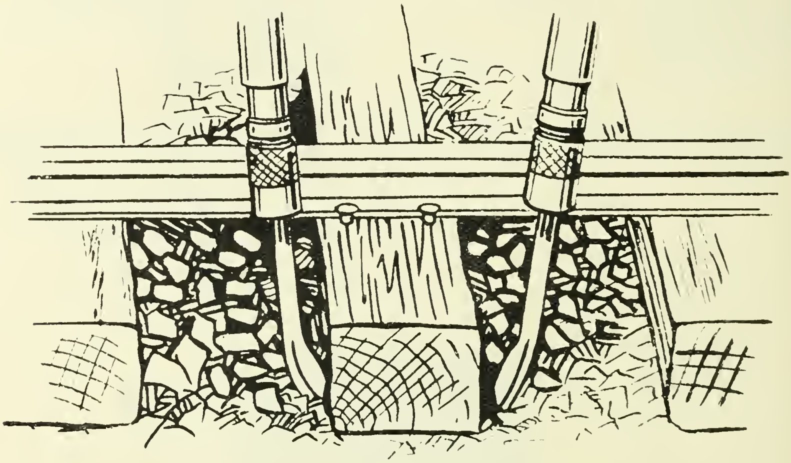

Fig. 4.

The handles are arranged to be held in the hands of the operator, so that the machine balances naturally in the correct position for tamping ties. It therefore does not tire the workman so much as hand tamping, as he can stand erect instead of in a stooped position as is required by either the tamping pick or bar, and also because he does not have to

exert himself in handling the tamper, but has merely to hold it loosely and guide it as necessary.

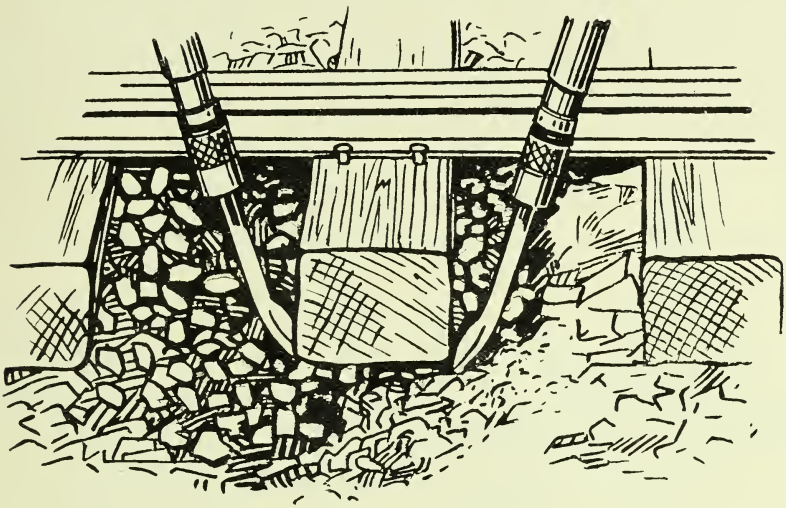

FIG. 5.

The tie tampers should be worked in pairs, one on each

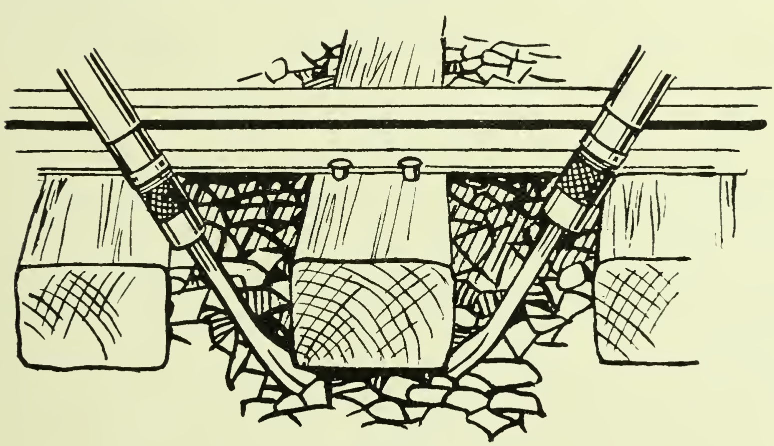

FIG. 6.

side of the tie and opposite each other (Figs. 4, 5, and 6), and should be held vertically when starting, with the broad face

of the bar against the tie until the face reaches the bottom of the tie, when both tampers should be swung back until they are at the proper angle to drive the ballast under the centre of the tie. Each operator should work under the rail to the end of the tie, and then lift back to under the rail and work to about 8 or 12 inches inside of the rail; he should not stay too long on one tie or he will overtamp and hump the track. The average speed of a pair of tampers working is about two minutes to a tie, that is, one minute outside of the rail and one minute inside of the rail.

If the tie is loose so that it bumps up and down under traffic, or the track is lifted out of face, it is not necessary to rake the ballast out from between the ties, as the tamping bar will work through the ballast. If the track is being tamped in face or the tie is fairly solid under traffic, it is desirable to loosen up the ballast with a pick before tamping, and in some cases it is necessary to rake out a little of the ballast, as it enables more speed to be made in tamping.

Gripping tight on the handles, throwing the weight on, or riding upon the tool, only tends to make it harder on the man and slow up the speed.

When tamping through slip switches or around frogs, crossings, and other places impossible to reach with picks or bars owing to the cramped space (Fig. 7), the tamping bar should be inserted through the space with the broad face parallel to the rail, and the machine held in a vertical position. It will run but a few seconds when it will displace a sufficient amount of ballast to permit of swinging the tamping bar around, so that the broad side parallels the cross tie; the machine should then be worked in the way already indicated.

In attempting to tamp such places by hand, there is a probability of mis-struck blows of the tamping pick or bar, which tend to sliver the edge off the under side of the tie

(Fig. 8); it is estimated that 35 per cent. of the deterioration of railroad ties is due to this cause.

As compared with hand tamping the pneumatic tie tamper has many advantages. With two men they will tamp as much track as eight men can do with picks or tamping bars, and the work done will last twice as long; owing to the present shortage of labour this is an important point. A test of rate work

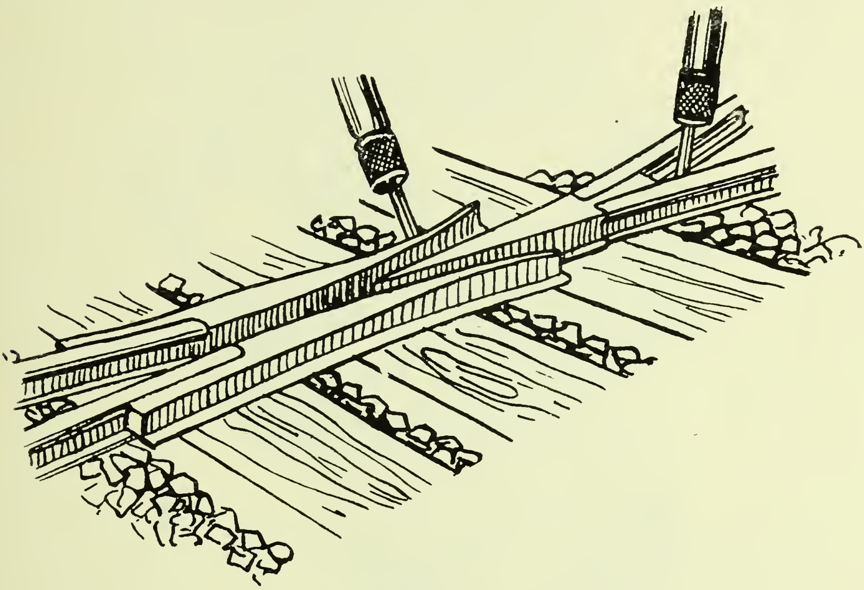

Fig. 7.

and costs by the two methods was made in 1916, in which the results of the work of five section crews at hand tamping were carefully observed and recorded for a week, as against the average results from the operation of five of the machines in regular operation. The work was in broken stone ballast, and the average cost per tie, using Imperial Tie Tampers, figured out at less than two-thirds of the cost of hand tamping. In this calculation the items of fuel, repairs, wages of machine operators and of foremen were taken into account, but not the overhead expense.

Owing to the tampers working in pairs opposite each other (as already mentioned), and by reason of the uniform air pressure, they strike a uniform blow which cannot be obtained by hand, due to the fact that a man's physical strength varies during the day. They tamp the ballast compactly under the tie, avoiding the formation of pockets, which in wet season

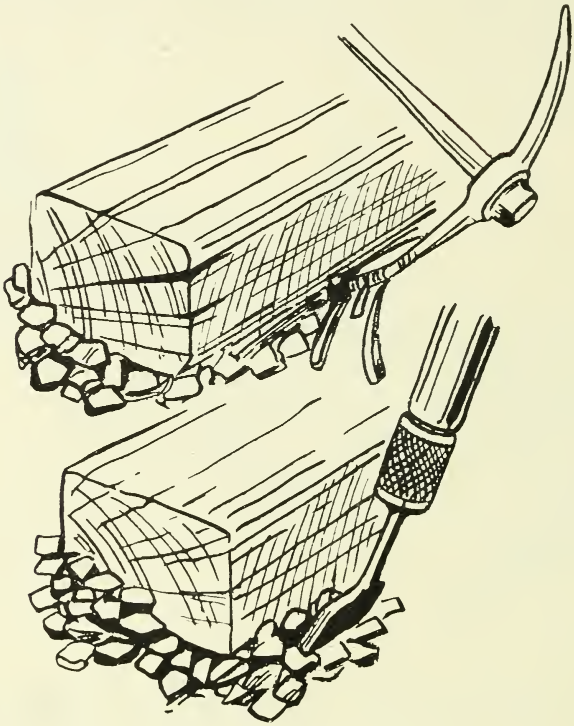

Fig. 8.

would hold water and cause a pumping tie with subsequent settlement (Figs. 9 and 10).

Since its introduction in 1913 the Imperial Tie Tamper has been adopted by 60 (sixty) steam railroads, and by 50 (fifty) electric railroads of the U.S.A. ; all told there are over 4000 tie tampers in actual operation. The following are the largest users :

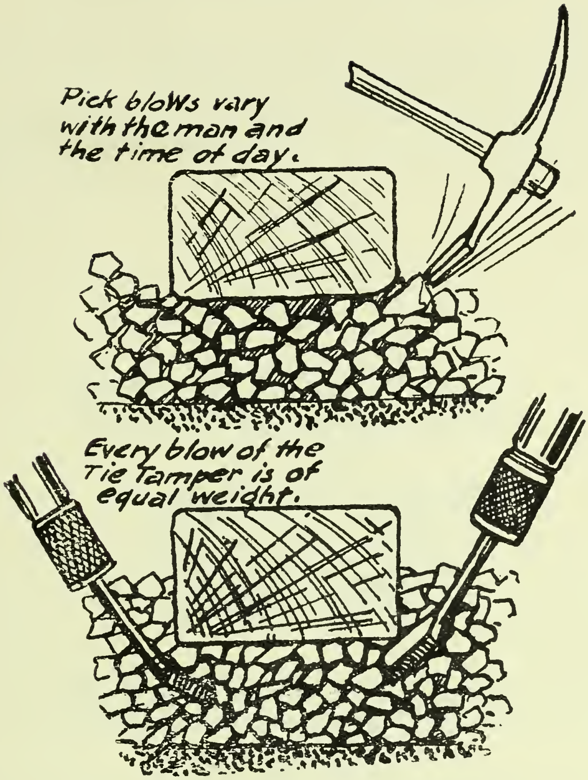


FIG. 9.

| | |
|---|---|
| New York Central (lines east of Buffalo) | 228 two-tool outfits. |
| ,, ,, (lines west of Buffalo) . | 47 four-tool outfits. |
| Delaware, Lackawanna and Western . | 62 ,, ,, |
| Pennsylvania . . . . . . | 40 ,, ,, |
| Baltimore and Ohio Railroad . . | 32 ,, ,, |
| Buffalo, Rochester and Pittsburg . . | 20 ,, ,, |
| Cleveland, Cincinnati, Chicago and St. Louis . . . . . . | 20 ,, ,, |
| Lehigh Valley . . . . . | 30 ,, ,, |
| Erie . . . . . . . | 27 ,, ,, |
| Illinois Central . . . . . | 11 ,, ,, |
| New York, Newhaven and Hatford | 6 ,, ,, <br> 10 two-tool outfits. |

The Pennsylvania Railroad has also about 1000 tie tampers worked from permanent air and signal lines.

There are no installations at present in this country, owing largely to the fact that the period which marked the develop-

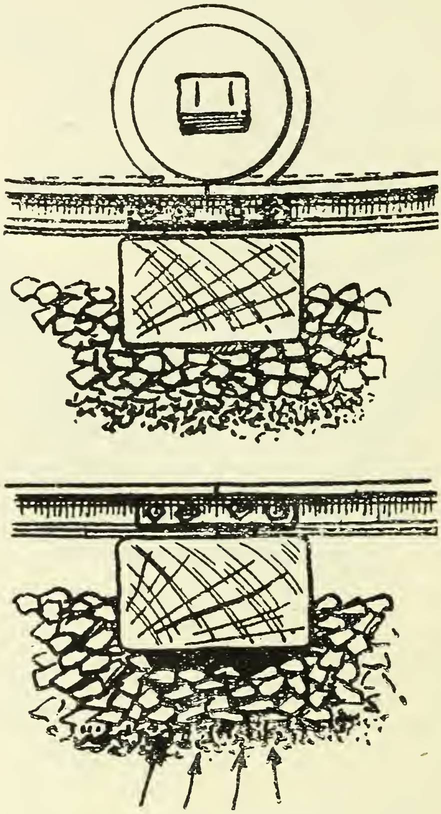

FIG. 10.

ment of the tie tamper in the United States has been one in which, under war conditions, British engineers have had little time to devote to the consideration of new machines of this sort; it seems, however, that the time has now come when any appliance likely to make for better and quicker work and for economy in labour cost should be given the fullest investigation and trial.

As the writer thinks it will be of interest to members, he gives in the form of an Appendix particulars of the use of the tie tamper by various railway companies in the United States of America.

## APPENDIX

### Tamping in Rock Ballast.

*Pennsylvania Railroad Company.*

The Pennsylvania Railroad has gone into the results produced by the Imperial Tie Tamper very extensively. The following is an extract from a paper read before a meeting of the Roadmasters' Convention in Chicago on Sept. 16 to 19, 1919, by Mr. J. B. Baker, Supervisor on the General Manager's Staff:

'*Surfacing.*—Hand surfacing is being replaced on many roads by the pneumatic tie tamper. This operation has been largely limited to stone ballast, but with larger faced bits there seems to be no reason why it should not be used to advantage in cinder and gravel ballast. One of the problems in the use of these tampers has been to train the men in handling the tool. When put in the hands of an inexperienced man these tampers are hard on the workmen, and the men at first shun their use, but when taught how to hold the tool properly, and after becoming accustomed to its working in general, very satisfactory results are being obtained.

'Experience has shown that best results can be obtained from the tampers by assigning a definite gang to their operation and allowing this gang to go from place to place over one supervisor's territory, rather than by passing the tampers

from one section to the next, in which case they would be continuously in the hands of inexperienced men.

'The Imperial Tie Tamping Outfits are too well known to require description here. The following is a comparison of the costs of machine tamping versus hand tamping, based upon the performance of these machines for several months, working exclusively in stone ballast. The cost is given in "tie parts," assuming four parts per tie, one inside and one outside each rail, and the expression "single" or "double" tamping refers to the tamping of a "part" on one side or on both sides of the tie :

'*Machine Tamping.*—One four-tool portable compressor outfit.

| | |
|---|---|
| Interest on investment, per day, at 6 per cent. . . . . | $ 0.57 |
| Depreciation on basis of 5 year life, per day, at 6 per cent. . | 1.61 |
| Repairs (from a 5 months' record), per day . . . . . | 0.94 |
| Gasoline, 2½ gallon per hour for 6½ hours at 27 cents . . | 4.39 |
| Oil, one quart, at 50 cents . . . . . . . . . | 0.12 |
| Wages, 5 men at 40 cents per hour, for 8-hour day . . . | 16.00 |
| | $23.63 |
| Number of tie parts double tamped per day . . . . . | 612 |
| Cost per double part tamped . . . . . . . . . | $ 0.038 |

'*Machine Tamping.*—Four tamping tools without compressor outfit—air taken from existing air line, for which no charge is made.

| | |
|---|---|
| Interest on investment, per day, at 6 per cent. . . . . | $ 0.08 |
| Depreciation on basis of 2 year life, per day, at 6 per cent. . | 0.61 |
| Repairs, estimated . . . . . . . . . . | 0.25 |
| Wages, 5 men at 40 cents per hour, for 8-hour day . . . | 16.00 |
| | $16.94 |
| Number of tie parts double tamped per day . . . . . | 612 |
| Cost per double part tamped . . . . . . . . . | $ 0.027 |

'*Hand Tamping.*—With picks, on a five-man basis.

| | |
|---|---|
| Depreciation and repairs, estimated, per day . . . . . | $ 0.25 |
| Wages, 5 men at 40 cents per hour, for 8-hour day . . . | 16.00 |
| | $16.25 |
| Number of tie parts single tamped per day . . . . | 320 |
| Cost per single part tamped . . . . . . . . | $ 0.050 |

'The above comparison is based on actual observations and represents the performance as done on the ground—that is, tamping is done on both sides of the tie in machine tamping (double tamped), and on one side of tie only in the pick tamping (single tamped). On the basis of 11,520 tie parts per mile of track (four parts per tie) the above comparison at $0.038 per part for machine tamping as against $0.050 per part for hand tamping represents a saving per mile of track of $138.24 in favour of the machine tamping; while on the basis of $0.027 per part for machine tamping as against $0.050 per part for hand tamping there is a saving of 0·23 cents per part or $264.96 per mile of track where air is available from existing air lines.

'No figures are available to show relative merits of the two methods of tamping, but all agree that machine-tamped track will maintain its surface for a considerably longer period than track put up by hand. There are many places where machine tamping is particularly desirable, notably through interlockings, and in the vicinity of water troughs where it is difficult to get men to work on account of the splashing of the water into their faces with every stroke of the pick.'

It will be noted that all figures for machine tamping are based on double tamping, but those for hand work are for single tamping only; consequently it may be conservatively stated that the actual saving afforded by the use of the Imperial Tie Tamper is double that shown in Mr. Baker's figures.

*Buffalo, Rochester and Pittsburg Railroad.*

*Method of Tamping Ties with Two Four-tool Machines.*—Average number of men: 24 men to two machines, including foreman and operator.

Twelve men and foreman ahead to raise track from 4 inches to 6 inches out of ballast to allow for new ballasting and also shovel tamp ties.

Eight men operating tampers follow up, four men tamping one tie, while the other four men tamp one tie with a sufficient space between so as not to interfere with each other. Ties are tamped outside and under rails, excepting at joints, where they are tamped 6 inches inside of rail.

Dressing up is done after tamping is done.

By this method this gang tamps an average of 999 feet per 8-hour working day.

Number of ties, 600. Labour, 40 cents per hour.

Operator paid 50 cents per hour in accordance with Supplement No. 4, covering men operating pneumatic tools.

The two four-tool machines are connected up as one unit with a $1\frac{1}{4}$-inch pipe line running in each direction 1100 feet.

The method of operating is used in connection with tamping stone ballast.

No method is used for comparison of cost of tamping by hand and machine tamping.

No. 2 machine used.

Average cost per tie, $0.145.

Average cost per foot, $0.088.

## *Atchison, Topeka and Santa Fé Railroad.*

OUR REPRESENTATIVE'S REPORT COVERING OPERATION OF TIE TAMPING MACHINE ON THE A. T. & S. F. DURING THE MONTH OF SEPTEMBER 1919.

| | | |
|---|---|---|
| Total working hours operated . . | 164 | 93% |
| Bad order . . . . . . . | 12 | 7% |
| Total . . . . . . . | 176 | 100% |

| | |
|---|---|
| Total labour cost machine operation . . . . . | $527.67 |
| Supplies, fuel and lubrication . . . . . . | 68.74 |
| Repair material . . . . . . . . . . | 52.97 |
| Labour repairs . . . . . . . . . . | 0.75 |
| Six per cent. interest on capitalisation . . . . . | 13.82 |
| One-twelfth of ten per cent. depreciation . . . . | 23.04 |
| Total operating cost . . . . . . . . | $686.99 |

| | No. of Trk. Ft. Tamped. | Cost per Trk. Ft. | Total Machine Hours. | Track Ft. per MachineHour | Total Man Hours. | Trk. Ft. per Man Hour. | No. of Ties Tamped. | AverageCost per Tie. | Avg. No. Ties Tamped per Machine Hr. | Avg. No. Ties Tamped per Man Hr. |
|---|---|---|---|---|---|---|---|---|---|---|
| [achine . . . | 13,135 | $0.052 | 164 | 80·03 | 1476 | 8·9 | 8757 | $0.078 | 53·4 | 5·9 |
| [and labour . ct. 1918 to date $1315.25 | 16,013 | 0.082 | ... | ... | 3163 | 5·06 | 10,675 | 0.123 | ... | 3·4 |
| ifference . . | ... | $0.030 | ... | ... | ... | 3·84 | ... | $0.045 | ... | 2·5 |

Above figures result of comparative work performed during September 1919, and work performed by hand, same crew, from October 1918 to October 31, 1919.

The PRESIDENT adjourned the discussion on this Paper to the next General Meeting, to be held at Cardiff on November 26, 1920. **The President.**

The proceedings closed with a vote of thanks to the President on the proposition of Dr. H. K. Jordan.

# PROCEEDINGS.

## Special General Meeting, Cardiff, November 26, 1920.

A Special General Meeting of the Institute was held at Cardiff on Friday, November 26, 1920, at 2.30 p.m., for the purpose of electing Dr. Henry K. Jordan, F.G.S., an Honorary Member of the Institute.

Mr. J. Dyer Lewis, the President, occupied the chair, there being a large attendance of members.

The appended Form of Recommendation by the Council for the election of an Honorary Member had been issued to members of the Institute :

FORM B.

THE SOUTH WALES INSTITUTE OF ENGINEERS.

(Founded 1857. Incorporated by Royal Charter 1881.)

Form of Recommendation by the Council

For the Election of an Honorary Member.

We, the undersigned, being not less than twelve Members of the Council, do recommend

Henry Keyes Jordan, D.Sc., F.G.S.,

as a fit and distinguished person to become an Honorary Member of the Institute, because of the valuable services rendered by him to the Institute. Dr. Jordan has been a member of the Institute since 1873, and during the whole of that period he has consistently advocated and supported its best interests. He has contributed many valuable papers to its ' Proceedings ' dealing with the Geology of the Coalfield, and his three papers on ' The South Wales Coalfield '—the last of which was published by the Institute in 1915—are recognised as standard works on this subject. His paper, ' Notes on the South Trough of the Coalfield, East Glamorgan,' was awarded the President's Gold Medal in 1904, this being the highest distinction the Council would grant to the reader of a paper.

He was elected President of the Institute for the Sessions 1897–98, and 1898–99.

And we accordingly present the said HENRY KEYES JORDAN for election by ballot at the Special General Meeting to be held on November 26, 1920.

J. DYER LEWIS, *President*.

ARTHUR J. STEVENS
HENRY WM. MARTIN
THOMAS EVENS
E. M. HANN
T. H. DEAKIN
WM. D. WIGHT
WILLIAM GALLOWAY
HENRY T. WALES
WILLIAM STEWART
HUGH BRAMWELL
JOHN FOX TALLIS
EDWARD DAWSON } *Past Presidents*

W. FORSTER BROWN
DAVID E. ROBERTS
WILLIAM JOHNSON
THEODORE VACHELL
W. A. CHAMEN
W. W. WOOD } *Vice-Presidents.*

GEORGE KNOX
DAVID HANNAH
T. ALLAN JOHNSON
FREDERIC BACON
THOMAS SUGDEN
HOWELL R. JONES
WILLIAM O'CONNOR
J. W. DAVISON
LEONARD W. LLEWELYN
TREVOR F. THOMAS
BENJAMIN NICHOLAS
F. LLEWELLIN JACOB
J. W. HUTCHINSON
CLARENCE A. SEYLER
EDMUND L. HANN } *Members of Council.*

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*Mode of Voting.*

If the name is objected to it must be crossed out. No enclosure is to be sent with this Form, which is to be returned to the Secretary, sealed without remark, before Friday, November 26, 1920.

The result of the ballot will be declared by the President at the Special General Meeting to be held on November 26, 1920.

MARTIN PRICE,
*Secretary.*

INSTITUTE BUILDINGS,
PARK PLACE, CARDIFF.
*November* 19, 1920.

The PRESIDENT: Gentlemen, we are met here this afternoon for the purpose of electing Dr. Henry K. Jordan, D.Sc., F.G.S., an Honorary Member of this Institute. As all of you have received the circular containing the recommendation of Council to that effect it will not be necessary **The President.**

The President. for me to read it to you. The scrutineers appointed by the Council for the purpose have made the following report regarding the election:—

We, the undersigned scrutineers, appointed for the purpose, having examined the ballot papers received, declare that Dr. Henry K. Jordan has been unanimously elected as an Honorary Member of the Institute.

Dated at the Institute, Cardiff, this 26th day of November, 1920.

(Signed) WILLIAM D. WIGHT }
EDWARD DAWSON } *Scrutineers.*

(Applause).

Dr. Henry K. Jordan, F.G.S. DR. HENRY K. JORDAN, who wore the robes of a D.Sc. (Wales) and the President's gold medal awarded to him in 1904, on rising to speak in acknowledgment was received with enthusiastic plaudits. He craved their indulgence on account of the fact that he had been unwell and had been confined to his bed for the most part of that week. He had been awarded a great honour and he was very proud of the position to which he had been elected. While he was proud of the honour which those robes represented he was also proud because the work which he had carried on almost continuously for forty years had been regarded as worthy of publication and study by members of the Institute, who were gentlemen competent to form a correct opinion. As a matter of fact he was indebted to the Institute almost more than to anything else. It was true that in the years gone by he had given some of his research results to the Geological Society, who, fifty-five years ago—in 1865—elected him a Fellow. However, he gave all he had done and ascertained to the Institute, and he did not regret it. It had been suggested that as he was the senior member of the Council—he was elected a member of

the Institute in 1873 and a member of the Council in 1876—it would be well if he narrated some of the events that had taken place in connection with the Institute since that time. In 1873 the Institute was a sort of peripatetic society, travelling about from place to place, holding its principal meetings at Merthyr and subsequently at Cardiff, Newport, and once, he thought, at Aberavon. Dr. Jordan proceeded to give many reminiscences of the early days of the Institute, which at that time had no permanent home, no library, and very few books. Two rooms were afterwards taken in premises in High Street, Cardiff, but a few nights after they had taken possession the building was burned down. They then got into rooms near the present Institute facing Queen Street. The Council afterwards considered the question of financing a building of their own, and his friends Mr. Arthur J. Stevens, Mr. W. D. Wight and two or three others warmly supported the idea. The late Lord Merthyr (then Sir William T. Lewis) was approached, and he interested the Bute Estate in the project, with the result that they secured a lease of the land upon which the present Institute was erected. Next came the question of finding the money and the kind of building which they required. Several of the members put their heads together and produced a sketch of their requirements. This was passed on to Mr. E. W. M. Corbett, who was appointed architect. The Institute was erected, being completed in 1894, and in course of time became too small for their needs owing to the influx of the coalowners. As a result, in order to enlarge the Institute, an adjoining plot of land was built upon. That was under the regime of one of their most brilliant mining engineers, Mr. E. M. Hann, for it was during his year of office as President that that was decided upon. Dr. Jordan went on to say that he was warmly interested in the work of the Institute from his first attendance at its meetings, and

**Dr. Henry K. Jordan, F.G.S.**

Dr. Henry K. Jordan. F.G.S.

this led him to continue the examination of the structure of the coalfield. He was perhaps not ill-qualified for such a task, seeing that he had previously investigated the structure of the Forest of Dean coalfield and afterwards did similar work in South Wales. He carried on that work until he had completed Part 3 of his monograph of the South Wales coalfield. As they were aware, the Institute readily accepted the expense involved in publishing that work. It contained a number of large drawings which were mounted on linen, and it was estimated that about 20,000 yards of linen had been put into the copies which were printed. He was pleased that the papers and drawings had evoked a considerable amount of interest in local collegiate circles, while Principal E. H. Griffiths had on two occasions paid him a great compliment in regard to them. Principal Griffiths had said—and he hoped he would not be considered conceited in repeating it—that if the Institute had done no more than publish those works it would have justified its existence. (Applause.) It was certain that he held his degree of D.Sc. because of what the Institute had done for him. It was the Institute who financed the publication of his monograph of the coalfield, and he never expected receiving such consideration at their hands. His friend Mr. Arthur J. Stevens in one of his characteristic letters said : ‘ We all know that your work was a labour of love without expecting any fee, favour, or reward.’ They would forgive him for saying so, but Mr. Stevens had never spoken a truer word. He (Dr. Jordan) rejoiced to see the progress made by the members not merely in numbers but in scientific investigation and results.

This remark recalled to his memory the saying of a favourite author, the late Charles Kingsley, who said in the concluding chapter of ‘ Two Years Ago ’ : ‘ When we rejoice in the progress of science we rejoice not in ourselves, not in our children,

but in God, our Instructor.' He quite agreed with Kingsley, and could say without hesitation that in his investigations he had met with many difficulties, some of which seemed insurmountable, but on bended knees he had sought for wisdom and guidance, and for any success he had achieved he rendered to that Beneficent Instructor profound thanks. (Applause.) **Dr. Henry K. Jordan, F.G.S.**

The PRESIDENT said that before handing the certificate to Dr. Jordan he would call upon one or two of the older members of the Institute to say a few words. They had certain letters of apology from absent members which he would ask the Secretary to read. **The President.**

The SECRETARY then read letters from Mr. Henry Wm. Martin, Mr. Thomas Evens, and Mr. E. M. Hann, Past Presidents of the Institute :—

Mr. MARTIN wrote : 'In reply to your letter of the 20th inst., I shall be very much obliged if you will convey to the President, Mr. J. Dyer Lewis, my great regret at being unable to be present at the meeting to confer the Honorary Membership of our Institute upon Dr. Henry K. Jordan, as I have an important appointment in London for Friday, the 26th inst. I am more than pleased that the members of the Institute have decided to recognise the splendid work done in the interest of our Institute by Dr. Jordan during the past forty-seven years. I sincerely hope that Dr. Jordan will be spared for many years to attend our meetings and give to the Institute, of which he has always been so proud, his very valuable advice and assistance.' **Mr. Martin.**

Mr. THOMAS EVENS wrote : 'Thank you for kind invitation to support the election of Dr. H. K. Jordan as an Honorary Member of the Institute. It would give me much pleasure to be present to take part in the ceremonial, but unfortunately I am not well and afraid to venture far away. It is the first occasion of conferring the Honour upon one of ourselves and **Mr. Thomas Evens.**

Mr. Thomas Evens.

upon a man of great ability and resource, who has given of his best during many years for furthering the interests of the Institute. His valuable geological contributions will always hand his name down to posterity as a deep thinker.'

Mr. E. M. Hann.

Mr. E. M. HANN wrote: 'I have your letter of the 20th inst. duly. I am exceedingly sorry to find that the meeting of the Institute for the election of Dr. H. K. Jordan as Honorary Member has been fixed for Friday next, as it will prevent me being able to attend as I should very much like to have done. Dr. Jordan's very eminent services to our Institute are, I hope, so well known to our members as not to require enlarging upon, but all the same I am very sorry that circumstances will prevent my taking part in this well-deserved tribute to him and to his valuable work.'

The President.

The PRESIDENT: I am very pleased to see present one of our oldest Past Presidents in Mr. Arthur J. Stevens, and I will ask him to speak.

Mr. A. J. Stevens.

Mr. A. J. STEVENS said he felt it a great honour and pleasure to be the first to voice their congratulations to Dr. Jordan on the distinction which they were bestowing upon him. He first met Dr. Jordan, very soon after his election as a member, at a meeting of the Institute in the old Town Hall at Newport, and from that day he was proud to be able to call him, and would always call him, his friend. Dr. Jordan, as they were aware, had spent his life in investigating the coal seams and their correlation in the different districts, and had done so as he, the speaker, had previously written, 'without seeking fee, favour, or reward.' It seemed to him that Dr. Jordan, in thus voluntarily and willingly giving of his best service not only to the Institute but to the whole of his fellow-countrymen, was deserving of their greatest gratitude. They heard a good deal nowadays of everyone working for himself, for money and so on, but in Dr. Jordan's case he had spent his

life in working for others and not for himself. He had his reward in that expression of the affection and respect in which they held him. He was sure Dr. Jordan felt the greatest gratification at that ceremonial and the feelings they expressed towards him. They only hoped he would have many years to look back on that day as a memorable one in his life. (Applause.) Mr. A. J. Stevens.

Mr. W. D. Wight, another Past President, said he could only endorse what the President had said in stating how pleased he was to see their senior Past President in the person of Mr. A. J. Stevens present that day. He was one of the very few who would remember Mr. Stevens presiding over that assembly. He was not only their senior Past President but, with the exception of two gentlemen, he was the senior living member of the Institute. The other two, he believed, were Mr. Joseph Hale of Cinderford, who had not attended for many years since he left the district, but he had maintained his connection with the Institute; the other was Mr. William Jenkins, late of the Ocean Coal Co., whom they all knew, at any rate by name if not personally. Mr. Jenkins, he was glad to say, was still to the fore, well and healthy. In being asked to speak in support of the election of Dr. Jordan as an Honorary Member, following after what had been said by Mr. Stevens and the letters from other Past Presidents, he was very much at a loss to do anything but echo the sentiments expressed. The work Dr. Jordan had done was so well known that he ventured to say that the 'Proceedings' containing his papers were more often referred to by the members than any other contribution which they had ever had made to them. (Hear, hear.) They were the standard work in the geology of the South Wales coalfield. Questions were continually arising among them as mining men in which they had to look up Dr. Jordan's papers to help them out. As had been said, Mr. W. D. Wight.

Mr. W. D. Wight. it was a labour of love, but it was labour on Dr. Jordan's part which occupied his attention for very many years, and no man except such as he could have persevered in the face of so many obstacles in overcoming the immense difficulties which he encountered. He was extremely pleased that Dr. Jordan at his age had been able to attend. He had turned fourscore years, and it was granted to few men to receive the honour that had been conferred upon him and to be in such a vigorous state of life as to be able to come there. (Applause.)

The President. The PRESIDENT: I would like to ask Mr. Westgarth Forster Brown to speak. I may say that he is our President Elect. (Applause).

Mr. Westgarth Brown. Mr. WESTGARTH BROWN said it gave him the greatest pleasure to have the privilege of speaking and supporting the election of Dr. Jordan. He fully endorsed, from his own knowledge, everything that had been said about Dr. Jordan's services to the Institute. Mr. Wight's difficulty was his also, and if anything more intense, as he had to rise after two other speakers. As a mining engineer he could judge perhaps more fully than some of the gentlemen who followed other branches of industry the great value of Dr. Jordan's geological work on that coalfield. It covered, as they all knew, practically the whole coalfield from Monmouthshire to Carmarthenshire. Dr. Jordan possessed a unique knowledge of the geology of the coalfield. That knowledge was acquired by original research largely and by hard work, and he had given it freely, not only to the members of the Institute but through them to the district generally. He knew that mining engineers and colliery managers engaged in developing the minerals in those valleys would agree that Dr. Jordan's works had been and would be in the future of the greatest value to all who had to do with that coalfield. He had known Dr.

Jordan a good many years, and he had always felt it a privilege to call him his friend. Before his (the speaker's) time, Dr. Jordan was a great friend of his father's, and he could imagine what pleasure it would have given his father to be present that day. He could only hope that Dr. Jordan would be spared for many years to come, and that they would see him amongst them often in the future. (Applause.) **Mr. Westgarth Brown.**

The PRESIDENT, before handing the certificate to Dr. Jordan, said : Only six persons have been elected as Honorary Members of this Institute, viz. : **The President.**

The present Marquis of Bute.

The present Earl of Plymouth (then Lord Windsor).

The late Viscount Tredegar.

The late Lord Kelvin.

The late Lord Merthyr of Senghenydd.

And now we elect our great friend Dr. Henry Keyes Jordan.

Dr. Jordan was being honoured that day by those who knew him best. The South Wales Institute of Engineers had unanimously elected him as a Honorary Member in token of the value of his work in the interests of the Institute for a very long period of years. The papers he had from time to time contributed formed a classical work on the geology of the South Wales coalfield, and they would remain as a monument to his skill and of his regard for the Institution for which they were written. He had had the pleasure and honour of his friendship since he was an articled pupil with Mr. James Brogden, who was one of the Past Presidents of the Institute. He had read all the papers Dr. Jordan had written, and he was studying one of them, 'Air Friction in Colliery Shafts,' at the time he sat for his examination. That, he believed, was one of Dr. Jordan's first papers, and he (the President) thought it was a wonderful contribution at that time, and indeed it still was. It was a great honour for him as President

The President. of the Institute to hand to Dr. Jordan the certificate of Honorary Membership, and it gave him the greatest pleasure in doing so to one of his oldest friends. (Applause.)

Dr. H. K. Jordan. Dr. JORDAN having signed the Roll, briefly acknowledged. He pointed out that that was the first occasion for ladies to be present at their meetings. He explained that on his own responsibility he had invited two ladies to come there that day. (Hear, hear.) He had brought his wife and she was accompanied by the wife of the President. He hoped that others would come in the future; he saw no reason why they should be excluded. If they encouraged the presence of the ladies they might have more young men to follow them. (Laughter.) It was a great pleasure for him to receive the certificate from the President, who was an old friend of many years' standing. He had known him before he became a member of the Institute, and he was very pleased to find him in the chair. Dr. Jordan, in concluding, said he was very grateful to the members for having accorded him such a high honour, of which he was very proud. (Applause.)

The proceedings of the Special General Meeting then terminated.

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## Ordinary General Meeting, Cardiff, November 26, 1920.

AT the termination of the Special General Meeting, the Ordinary General Meeting of the Institute was held, the President, Mr. J. Dyer Lewis, being in the chair.

The Secretary read the Minutes of the Ordinary General Meeting held at Swansea on September 30, 1920, and of the Special General Meeting held at Cardiff on October 7, 1920, and they were confirmed.

## Election of Members.

The following candidates for admission to the Institute were declared duly elected :—

*As Members.*

| | |
|---|---|
| Ball, Harry Standish, M.Sc. . | Doncaster. |
| Burnip, William . . . | Penhill, Cardiff. |
| Davies, Tudor . . . | Dowlais. |
| Davies, William James . . | Llandebie, Carm. |
| Harley, Gordon, A.M.Inst.C.E. | Penarth. |
| Jones, Thomas John . . | Brynmawr. |
| Rees, Benjamin Edgar . . | Swansea. |
| Watson, Geoffrey Lewin . | Cardiff. |
| Williams, Idris James . . | Merthyr Tydfil. |

*As Associates.*

| | |
|---|---|
| Griffith, Richard Silvanus . | Ystrad Mynach, near Cardiff. |
| Jones, Emlyn W. . . . | Aberdare. |
| Lewis, Reginald Gordon . | Mardy, Rhondda. |
| Powell, Tudor . . . | Efail Iraf, near Pontypridd. |
| Thomas, Gwilym David . | Bridgend. |

*As Student.*

| | |
|---|---|
| Kyte, Gordon William . | Whitchurch, near Cardiff. |

## Admission of New Members.

The following gentlemen, who had been previously elected, signed the Roll Book and were admitted to the Institute :—

*As Members.*

| | |
|---|---|
| Hall, James . . . . | Neath. |
| Jones, C. Godfrey. . . | Waunllwydd. |

| | |
|---|---|
| Roberts, T. W. Harcourt . | Haverfordwest. |
| Seymour, H. W. . . . | Pontyberem. |
| Williams, I. J. . . . | Merthyr Tydfil. |

*As Associates.*

| | |
|---|---|
| Abbott, W. P. . . . | Tredegar. |
| Griffith, R. Silvanus . . | Ystrad Mynach. |
| Hackett, J. H. . . . | Newport, Mon. |

**The President.** The President announced that the Council had unanimously elected Mr. Westgarth Forster Brown as President for the ensuing session. He did not think they could have had a better man to fill the chair. Mr. Westgarth Brown had been bred and born in Cardiff; he was an eminent mining engineer who had made a thorough study of the whole coalfield. As they were aware, his father, the late Mr. T. Forster Brown, was a Past-President of the Institute, and besides being a very regular attendant at the meetings, had contributed several papers to their 'Proceedings.' Many would remember the paper read by him as far back as 1870, and it was still regarded as one of the standard papers on the South Wales coalfield. Now that Mr. Westgarth Brown had been elected, he asked the members to give him a hearty welcome. (Applause.)

**The President-Elect.** Mr. Westgarth Forster Brown, who was received with acclamation, said he was very much obliged for the support given to the announcement that he was to be made their President for the coming year. He could only trust that he would carry out the duties efficiently and to their satisfaction. (Applause.)

## Notes on a New Type of Colliery Tram.

By W. D. Woolley.

(Paper, *see* Proceedings, Vol. XXXVI., No. 1, p. 165.)

Further discussion was invited on this paper.

Mr. G. D. Budge said he had read the paper with great interest. In the first place he agreed with Mr. Woolley when he said that the only dust-proof tram was the box tram. He did not, however, think it was possible to make a tram, with a door, that was dust-proof. He remembered making some trams for conveyor work, and the specification stipulated that they should hold water. They were all filled with the water when they came on the job, but were condemned, for after the first run underground they were no longer water-proof or dust-proof. As a matter of fact, when they talked about 'dust-proof' it could only be in a comparative sense. The tram which had been in use at the Markham Colliery, of which a description was given in Mr. Woolley's valuable paper, appeared to him as adequately meeting the requirements of Section 62 of the Mines Act. He wished, however, to ask Mr. Woolley what his actual experience had been in the way of opening the door of that tram after it had been running for some time and after it had been in two or three smashes. He would like to know whether he found much evidence on the door of the tram of a pick being used to lever it open. That had always been his experience of a door which had to be raised before being thrown open. A door which was going to make a good job—that was, a really close fit, was quite impossible under colliery conditions. They must admit that sufficient allowance had to be made for the strain which colliery trams were subjected to. When they came to think of dust which would pass through a mesh of 120 sieve and when they **Mr. G. D. Budge.**

Mr. G. D. Budge.

remembered clearance to meet colliery conditions, of over a quarter of an inch or something like that, he thought they had to face it and see that their efforts were more directed towards preventing the escape of small lumps of coal. He was anxious to hear from Mr. Woolley to what extent he had been successful in preventing the smaller particles of coal escaping on to the roadway. He knew that the largest quantity of dust in a colliery was made by the action of the wheels of the trams grinding the coal which fell out of the trams on to the rails. The best test of the efficiency of a tram was, in his opinion, proved by the condition of the haulage roads—the haulage roads over which this type of tram was being used. Mr. Woolley had had this tram in use at the Markham Colliery for some time, and he (Mr. Budge) thought it would be of very great assistance to them if he would say whether he had found any marked reduction in the quantity of dust on the roads of the Markham Colliery compared with the roads of collieries where the old type of tram was in existence. He thought it was a very valuable paper, and one that was very much needed at the present time. Mr. Woolley had tackled the subject in such a way as to be of great help to colliery people all over the coalfield. (Applause.)

The President.

The President said he would like to say a few words before calling upon Mr. Woolley to reply. As all who were connected with collieries were aware, the greatest amount of damage to colliery trams was done not in the coal filling, but during the repairing shift, when huge lumps of stone were often thrown into them by the repairers. The trams were knocked about in consequence far more than in the coal shift. He thought it was impossible to make a dust-proof tram in the form made in South Wales to-day. He noticed that in the North of England they had started making trams in quite a new method—of aluminium in the box fashion, so

that there was absolutely no chance of dust getting out of it. He did not know whether they would be successful, but he was sure they would not be a success in South Wales, and besides, they were very expensive. The President.

Mr. W. D. Woolley, in reply, said he had pointed out at the end of his paper that he did not put forward this tram and door as being perfect, but rather for the purpose of inviting criticism and therefore obtaining further ideas. He would have liked more criticism of the tram, because he was not at all satisfied that its door was perfect. He had had more experience of the tram since the paper was read, and he was not satisfied with the door as originally designed. They had since tried a tram, generally of the same design, but with a swing or hinge door, which, of course, was on the outside of the angle iron end binder. The door was of stiff design, and this end of the tram was also reinforced by a plate about 4 inches high above the bottom of the tram riveted to the two sides of the end binder. That tram had been very successful so far. Mr. W. D. Woolley.

With regard to the opening of the door after a smash, there was not much difficulty. They found that the men did not lever the door at the bottom, thereby damaging the same, but raised it up by levering the binders at the top on the bar. He could say quite definitely that with regard to preventing the escape of small lumps of coal, there had been a material improvement in that direction.

At one colliery where they now had these trams, there was a main incline about a mile long; the journeys travelled there very quickly, and it was always a source of trouble to keep the incline clean, owing to the coal falling from the trams and being ground into dust. Since they had been using these trams there had unquestionably been a marked improvement. Some time ago the 'Clip-Tub' type of tram was brought to their notice. They were made of pressed steel plates, and inter-

Mr. W. D. Woolley.

locked together, but not riveted. So far, they were only made in box fashion. They had offered to try those trams, but owing to the high cost of making a small number of them, due mainly to the fact that for each size of tram special moulds, etc., had to be made to be used in the hydraulic press in which the plates were moulded. They therefore obtained a few bodies of type and size of tram which were being built for the Cronton Collieries in Lancashire and put them on their own frames. These were perfectly satisfactory, and had been going for six or eight months and had not cost a penny in repairs.

They were considering trying a box tram of that description of their own dimensions, but still there was the difficulty of the door. (Applause.)

On the proposition of the President, Mr. Woolley was heartily thanked for his interesting paper, the discussion of which was closed.

## Recent Developments in Gas-Firing Steam Boilers, and in the Utilisation of Waste Heat, on the 'Bonecourt' System.

By Major W. Gregson (late R.E.), B.Sc., A.M.Inst.C.E., A.M.I.Mech.E.

Consideration was given of the paper by Major W. Gregson on this subject, and the President invited Mr. Sugden to open the discussion.

Mr. Sugden.

Mr. T. Sugden said the cheap production of power was at all times a matter of importance, but with the present excessive cost of fuel it was a matter of supreme importance, and consequently any honest attempt in this direction was worthy of consideration. The 'Bonecourt' system possessed severa novel features, which when fully developed might effect great economy. The system was, however, still in its infancy, and many improvements would have to be made before it became

a practical success. The 'Bonecourt' system of firing steam boilers was practically confined to gas, waste heat and oil, and was limited to a special design or type of boiler, viz., fire-tube boilers. The principle had so far not been applied to water-tube boilers. The chief feature of the 'Bonecourt' system of gas firing consisted of splitting up the gases and providing one burner for each tube. In the type of boiler described there was no fire-box or combustion-chamber. Whilst not disputing the claims made for the 'Bonecourt' system, it must be admitted that they were somewhat startling when compared with best modern practice. The air pressure was somewhat excessive; at times it was stated to be as much as 10 inches water-gauge pressure. [Major Gregson: Suction, not pressure.] The boiler efficiency claimed, viz., 92·5 per cent., was far in advance of the best modern boiler practice, which barely exceeded 75 per cent. efficiency under normal conditions. Another very special feature of the boiler was the large amount of water evaporated per square foot of heating surface. In water-tube boilers 4 to 5 lb. of water were evaporated per square foot of heating surface under normal conditions, whilst a square foot of Lancashire boiler heating surface would evaporate 7 to 8 lb. The 'Bonecourt' boiler, it was claimed, would evaporate 35 lb. per square foot of heating surface, which was 300 to 500 per cent. more than was obtained in modern boiler practice in the types of boilers referred to. The claim to high efficiency of 92·5 per cent. should be supported by better evidence than was given in the tests made, which were very meagre. No analyses were given of the escaping gases passing to the chimney. This was important, as it might put a very different construction on the results. There was always a way of finding out what had been spent by seeing what they had left. The high rate of evaporation per square foot of heating surface, viz., 35 lb. per square foot (see Appendix III) suggested extremely excessive temperatures in some parts Mr. Sugden.

Mr. Sugden. of the tubes—that was, the point of maximum activity. It might be observed that high-rated evaporation was generally accompanied by increased wetness of steam. Some time ago a French engineer constructed a very ingeniously arranged experimental boiler to determine the distribution and evaporation per foot length of fire tube. The boiler was constructed in nine separate compartments, covering the whole length of the fire tubes; in this way the evaporation of each compartment could be readily measured. The following results were obtained :—

| | |
|---|---|
| *Fire Box* | 38·1 |
| 1st Section | 17·2 |
| 2nd ,, | 11·2 |
| 3rd ,, | 8·6 |
| 4th ,, | 6·7 |
| 5th ,, | 5·3 |
| 6th ,, | 4·3 |
| 7th ,, | 3·4 |
| 8th ,, | 2·8 |
| 9th ,, | 2·4 |

It was quite evident that this was a very accurate method of getting at the evaporation which takes place in the various parts of a boiler. From those results it would be observed that about three-fourths of the evaporation was done in about one-third of the length of the tubes. Under such working conditions it was quite evident that the life of the tube would depend upon the purity of the feed water and the absence of scale or oil films on the outside of the tubes. The iron spiral core which constituted a distributor, heat radiator, and conductor, may work without giving any trouble providing the boiler is fired either with clean gases or oil, but when working with gases containing dust, difficulties would arise. Similar spiral cores had been used in Scotch marine boilers, but it had always proved a difficult problem to clear away

the flue dust. The importance of keeping the tubes clean directly affected the efficiency of the boiler. Further, trouble arose in connection with flue dust from boilers where the air was supplied by means of forced or induced draught. The amount of dust escaping in the surrounding area created a nuisance, and in some districts the local authorities prohibited the use of such boilers owing to the dust nuisance. This evil was certainly intensified by a short chimney shown in the 'Bonecourt' boiler. In Plates II, III, and IV were shown boilers fitted with superheaters, but no mention was made of the degree of superheat obtained. The efficiency claimed for the 'Bonecourt' boiler was due to the low temperature of the escaping gases passing from the boiler. In the test given on p. 304 the temperature of gases leaving the boiler was stated to be 384° F., the temperature of steam being 335·5° F. This left a difference of only 48·5° F. available for superheating, which was no use. That is to say, either the superheater would not be of any service or the boiler efficiency claimed could not be obtained with the arrangement of superheater shown on Plates I, II, and IV. Mr. Sugden.

Major GREGSON: The boiler on which that particular test was made was not fitted with a superheater. Major Gregson.

Mr. SUGDEN replied that there were several references to it, but no results were given. He proceeded to say that under such conditions of working not a single degree of superheat would be obtained, as the heat available would not be sufficient to absorb the moisture in the steam. His experience was there should be at least a difference in the temperature between the heat available for superheating and the steam to be superheated of 400° to 500° F. Presumably the arrangement shown on Plates II, III, and IV of the combined plant of boiler, superheater, and feed-water heater was only a suggested design and no plant was actually at work. A superheater Mr. Sugden.

Mr. Sugden. could no doubt be arranged to meet the working conditions, but it must be placed at that part of the boiler where there would be an available temperature of about 1000° F. If a superheater was attached to this design of boiler, it would reduce the boiler efficiency, but in order to obtain engine efficiency and also other advantages it paid to rob the boiler for that purpose. A superheater could be supplied to this boiler, but not the type that was shown. One of the best features of the 'Bonecourt' boiler was the method of splitting up the gases by igniting the gas to each tube. The air control appeared perfect for a constant flow, but with a variable load the efficiency would fall away unless some mechanical device could be adopted to adjust simultaneously a proper proportion of air and gas, which was a very difficult problem, and in making the adjustments from time to time, more skill would be required than could be expected from an ordinary boiler attendant, but probably this difficulty would be overcome in due course. The proposed construction of large units where one boiler was placed immediately over another, was a method which would appear to involve some difficulty in regard to the boiler feed. The method suggested was rather a novel one, where the water in the upper drum overflows at a certain level to supply the lower drum. There were no water gauges on the top, only on the lower. If that design of boiler was in actual use, it would be interesting to know how this system of boiler feeding worked. Under the heading of 'Utilisation of Waste Heat,' pp. 292 and 293, reference was made to 'Bonecourt' boilers fired with the exhaust from gas engines; such gases formed a highly corrosive compound, which attacked the fire side of the boiler tubes and plates so rapidly as to ruin the boiler in a very short period. In some cases boilers so fired had been condemned as unsafe after working about twelve months, and for that

reason did not find favour with boiler insurance companies. This objection was, of course, common to all types of boilers fitted with exhaust from gas engines. Perhaps the author would state his experience on the point. The records of tests made in the paper were not sufficiently complete to be of any real value, and that remark also applied to the time occupied in testing, which was only a matter of a few hours. Boiler tests made under such conditions not infrequently proved misleading. The test appeared to have been made at the point of highest efficiency and not under variable loads, which always affected efficiency tests. There were good points in the boiler, and it was to be hoped that further developments might overcome the difficulties which at present stood in the way of this system being more generally adopted. **Mr. Sugden.**

**Professor F. Bacon.**

Professor F. Bacon said everyone would agree that any system of firing boilers which afforded the possibility of maintaining a heat efficiency of the order of 90 per cent. ought to receive most careful consideration. He had read Major Gregson's paper with the greatest interest, and he considered it a very valuable contribution to the 'Proceedings,' as it explained clearly and concisely the important simplifications and improvements introduced into the 'Bonecourt' system during the last four years. It was clear that the present-day 'Bonecourt' boiler was something entirely different from the early gas-fired surface combustion boilers described by Professor Bone before the war. The early example of 'Bonecourt' boiler installed at the Skinningrove Ironworks in 1911 consisted of a cylindrical drum 10 feet diameter and 4 feet from back to front, traversed by 110 steel tubes of 3 inches internal diameter. An up-to-date design to give approximately the same output was shown in Plate I of the author's paper. It took the form of a shell 4 feet diameter fitted with tubes 15 feet long. But the changes involved did not end with this striking change

Professor F. Bacon.

in proportions. The chemical and physical conditions attending combustion had been profoundly modified. Instead of projecting an explosive mixture against a catalysing surface of incandescent refractory packing resulting in flameless surface combustion, they were now using burners in which combustion took place by flame in the ordinary way. There was no longer any admission of primary air, and the gas had to find all the oxygen necessary for its complete combustion after leaving the burners. He would like to put it to Major Gregson as a direct question whether this change-over to burners of more ordinary type was not really tantamount to abandoning the principle of surface combustion altogether.

It was well known that in ordinary boiler practice some 97 per cent. of the total temperature head was expended in driving the heat through a thin but feebly conducting stagnant gas film which clung to the inside walls of the fire-tubes. Although the gas film was such a bad conductor of heat, it was practically transparent to radiant heat. Professor Bone had laid stress on this fact, pointing out that in his early gas-fired surface combustion boilers a very high proportion of the total heat reaching the water penetrated the gas film in the form of radiant energy to which the film offered little or no resistance. In the present-day 'Bonecourt' boiler it was clear that this supposed advantage had been largely sacrificed, for according to Major Gregson's own figures, the peak temperatures attained by the packing had been reduced from 1450° C. to 800° or 850° C. Applying Stefan's law, which asserts that radiation is proportional to the fourth power of the absolute temperature, it followed that the maximum rate of radiation from the packing to the tubes had been cut down to 18 per cent. or less of its former value. In view, then, of the fact that the latest 'Bonecourt' boilers gave unimpaired results as regards efficiency and evaporation per square foot

of heating surface, he would like to ask whether it was right to conclude that the advantages due to surface combustion and increased transmission heat by radiation had not proved to be largely imaginary, since equally good results were obtainable without recourse to these special features, the introduction of which had involved attendant difficulties of a practical character. Professor F. Bacon.

Professor Bone had published a diagram showing the heat gradient along the 3-foot tubes fitted with refractory packing used in his early experiments. It would be most interesting if Major Gregson could give the approximate form of the heat gradient along the present-day 15-foot tubes, (1) in which the iron spiral ran from end to end, (2) in which the iron spiral stopped short half-way along the tube. Comparison between these would exhibit what sort of influence the iron spiral had on the temperature distribution beyond the zone of combustion. He supposed he was correct in thinking that the temperature of the products leaving the far end of the tubes could be adjusted within limits by varying the length of iron spiral inserted at the front end of the tubes.

In the early form of boiler in which each burner was under individual control, it was possible to steam at light loads by having a reduced number of burners full on while the remainder were turned off completely. He (Professor Bacon) thought this an unwise plan to adopt, as it would subject the tube plates to severe racking strains; but it evidently did provide a means of securing practically full-load efficiency at light loads. It was explained that in the boiler as now designed the whole of the gas adjustment was accomplished by a single valve which reduced all the burners equally. He would like to know whether much had been sacrificed as regards efficiencies at light loads by the adoption of this simplified system of gas control.

Professor F. Bacon.

As Mr. Sugden had already pointed out, it was obviously very important to keep the amount of air admitted in correct relation to the gas supply, and he would like to know how the boiler attendant was able to tell when the speed of the fan was correctly adjusted to give perfect combustion for any given opening of the gas valve. It was stated in the paper that the power taken by the motor-driven fan was only 1 per cent. to 3 per cent. of the output of the boiler. Seeing that suctions as high as 10 inches of water were employed, this seemed rather a small allowance, and he would like to know on what steam consumption per fan-horse-power the figures were based. Lastly, when boilers were installed to utilise the heat going to waste in the exhaust from internal combustion engines, did the 'Bonecourt' system provide any means of recovering the low temperature heat rejected to the water used in the cylinder jackets?

Mr. J. W. Davison.

Mr. J. W. Davison said he happened to be at the Skinningrove Ironworks about three years ago, and in passing through he noticed the 'Bonecourt' boilers, but they gave one the impression that they had not been working for some time and had been scrapped. He would like to ask Major Gregson if he could state the reason why those boilers were not working at that time.

Major W. Gregson.

Major W. Gregson in reply first dealt with the question asked by Mr. Davison. He had been trying (he said) to show that the Skinningrove boiler was as far removed from the 'Bonecourt' boiler of to-day as it was possible to imagine. The reason, however, why the boiler was out of commission at the time of Mr. Davison's visit was that the works were being changed over from the manufacture of poison gas. He had been informed that the boilers had otherwise been in continuous operation ever since they were put in, in 1911, as he had previously stated at the Swansea meeting. He stated that Mr. Sugden had asked whether it was possible to extend

'Bonecourt' principles to gas-fired water-tube boilers. He (Major Gregson) explained that this was not feasible, as the essential principle involved was perfect molecular contact between the combustible gas and the oxygen needed for its combustion, and this could only be obtained within fire tubes. **Major W. Gregson.**

Replying to a question as to the effect of dirty gas on the iron spirals, he remarked that no trouble had been experienced in gas firing; the draught either carried the dust through the tubes or, if the dust was of a tarry nature and attempted to adhere to the spiral packing, it was promptly burnt up on the incandescent surface. In certain cases of the utilisation of waste heat, as mentioned in the paper itself, spirals were not used, the boiler tubes being suitably proportioned to maintain the high efficiency. Mr. Sugden asked what was the maximum superheat obtainable and how the correct temperature for superheat was obtained in the chamber between the boiler and economiser. The author of the paper explained that any desired temperature in the range between the maximum temperature in the boiler tubes and the outlet temperature of the economiser was obtained by suitably adjusting the spiral packing in the boiler; when moderate superheat was required, a greater percentage of the heat was abstracted from the gas in the boiler and the economiser had comparatively small work, but when high superheat was required only a small proportion of the sensible heat was taken out of the gases in the tubes of the boiler, and the economiser then became practically a second boiler and extracted the remainder of the available heat from the gases. Total steam temperatures of 700° F. were easily obtainable, and at the same time the high efficiency of the boiler unit was kept up. Replying to a point raised as to whether skilled attention was necessary to run a battery of these boilers, it was pointed out that the boilers were practically self-controlled. The author also pointed out that the 'Bonecourt' waste heat boiler had eliminated

Major W. Gregson.

that greatest defect connected with waste heat boilers, i.e. corrosion troubles, owing to the fact that rapid steam generation reduces the period of tube 'sweating' to a minimum, and the perfect control of the outlet temperature enabled the user of the boiler to always keep above the critical temperature of corrosion at the outlet tube plate. The leading boiler insurance engineers were perfectly satisfied with these boilers and regularly accepted them for insurance.

Furthermore, Major Gregson stated that the boilers illustrated in the Plates all represented types either at work or under construction, and that the various arrangements shown thereon had all proved themselves in practice; also that a table had been added in his supplementary remarks which gave Mr. Sugden the outlet products analyses he required.

Replying to Professor Bacon's remarks, Major Gregson concurred in the statement that the present-day 'Bonecourt' boiler operated on very different principles from the original boiler as first brought out by Professor Bone, as the principle of surface combustion was no longer applicable, and the lowered peak temperatures had rendered the transmission of heat by radiation much less than obtained in the earlier types of 'Bonecourt' boiler, such as represented at Skinningrove. The essential feature of the present gas-fired boiler was the intimate mixing between air and gas and the constant contact of the hot gases with the heating surface of the boiler, together with a suitably proportioned heating surface to deal properly with the heat in the gases. Both Professor Bacon and Mr. Sugden had raised the question as to whether full-load efficiency was obtained at light loads, and Major Gregson pointed out that this was done by synchronising the gas pressure and the suction for all loads by means of simple valve manipulation. A further question raised was as to the power taken by the motor-driven fan, this being apparently very small; the

author pointed out that this was so owing to the fact that the fan was dealing with comparatively small volumes of gases, as the waste gases contained practically no excess air, being simply the theoretical constituents of the products of complete combustion. Professor Bacon asked whether any system had been evolved whereby the jacket water from internal combustion engines could be used for feed water for the waste heat boiler, and Major Gregson stated that a plant was in course of erection in which this principle had been adopted. **Major W. Gregson.**

Regarding Professor Bacon's question as to the effect of various arrangements of packing in the tubes, this was such a big question that he (Major Gregson) could not possibly deal with it in the scope of a short descriptive paper, but he hoped at a later date to publish some of the figures obtained in experimental and actual practice, together with particulars of fuller tests in plants installed under typical industrial conditions. He was afraid that lack of time prevented his going further into details during the present discussion.

Mr. W. H. Reynolds writes :— **Mr. W. H. Reynolds.**

At the meeting at which the paper was read I questioned the statement the author made to the effect that it was common practice to raise steam in 'Bonecourt' boilers from cold water to full pressure in thirty minutes. I criticised the saneness of the practice rather strongly, and although I did not intend my remarks to be taken too literally, I confirm that with the exception of the smaller sizes of 'Bonecourt' boilers, as used in laboratories, etc., I am sure such rapid steam raising would be very detrimental to boilers of this design and construction, especially the multiple drum type.

The paper is very interesting and, I think, a valuable addition to the records of the Institute, but I venture to submit

Mr. W. H. Reynolds.

that the author is, to a certain extent, carried away by his own enthusiasm, because some of the remarks do not appear to me to be borne out by actual experience. I must point out here that I do not doubt the comparatively high thermal efficiencies claimed for the 'Bonecourt' boiler when coke-oven gas or producer gas is used, and I agree that under these conditions of firing the 'Bonecourt' boiler has many advantages. With coke-oven gas the temperature of combustion is high and, in consequence, the mean temperature difference through the boiler itself is good; therefore the principle of radiation and surface combustion with fire tubes should be satisfactory. In coke-oven gas firing also, the weight of gases being dealt with is moderate. Therefore the power required by the fan is not such a great item, and the area through the boiler required for minimum drop in draught can be obtained in reasonable diameters. On the other hand, when utilising waste heat from steel furnaces, the conditions are quite different owing to the very large volume of gases at low temperatures which the boiler is required to deal with.

It is not clear to me from the paper that 'Bonecourt' boilers have actually been installed in connection with open-hearth furnaces. The illustration on p. 298, Fig. 8, appears to be misleading: it is stated that this size of waste heat boiler was erected to utilise the outlet gases from a steel furnace, and that this particular unit works under natural draught conditions. I beg to point out here that the paragraph describing this boiler follows immediately on a description of the saving to be obtained by utilising the waste heat from open-hearth furnaces. I am well aware, from my knowledge of boiler plants (not 'Bonecourt') installed during the past few years in conjunction with open-hearth furnaces, that valuable savings can be and are being obtained, but not under natural draught conditions.

I am sceptical about the boiler illustrated by Fig. 8, working in conjunction with an open-hearth, as described, because an open-hearth furnace requires not less than $1\frac{1}{2}$-inch water-gauge at the regenerative chequers, and this could not be obtained under natural draught conditions with the interposition of such a boiler as that illustrated. **Mr. W. H. Reynolds.**

The author mentions $2\frac{1}{2}$-inch water-gauge as being the standard for a boiler with induced draught. In view of the experience gained from water-tube boiler units actually utilising waste heat from open-hearth furnaces, it is difficult to believe that the 'Bonecourt' type of boiler utilising waste heat will only drop $\frac{1}{2}$ inch in the draught; more likely with the boiler alone the 2 inches stated is taken up entirely in the boiler and the fan will have to deal with $3\frac{1}{2}$ inches at least. I may say that it is generally necessary to have about 4 inches at the fan.

On p. 295 a 35-ton furnace—open-hearth—is mentioned with a coal consumption of 3000 lb. per hour and an evaporation of 8400 lb. Basing on this evaporation being from and at 212° F., it means a gas temperature reduction of from 1000° F. to 425° F. From various tests actually made on open-hearth waste heat boiler plants, 3000 lb. of coal would mean about 60,000 lb. of gases, and at the mean temperature through the boiler of 712° F., the mean volume passing through the boiler would be 490 cubic feet per second. It seems to me under these conditions the 'Bonecourt' units would require a large number of tubes in order that the considerable area necessary for this gas volume would be available, especially in view of the fact that the 'Bonecourt' tubes are partly filled with refractory material or contain spiral metal retarders.

Several of the open-hearth furnaces of which I have particulars, in conjunction with waste heat boilers, are of about 70 tons capacity, and on many of the waste heat boilers installed, and about to be installed, the weight of gases to be dealt with

Mr. W. H. Reynolds.

is as much as 110,000 lb., at about 900° to 1000° F. It would appear, therefore, that the size of 'Bonecourt' unit to suit the open-hearth furnace conditions I mention would have to be considerably increased in order to get the necessary area for the passage of the gases, and I suggest that this would mean either returning to the very large diameter drums, as originally installed, and which, according to the paper, have since been discarded as unsatisfactory, or multiplying the drums as shown on Plates III and IV, which, I take it, are more or less experimental at present, and which I do not think is an arrangement to be recommended.

I might mention that I used exactly similar metal retarders to those described in the paper, in the return tubes of multi-tubular boilers, eighteen years ago. The reasons for their use then were similar to those given under 2, 3, and 4, on p. 284 of the paper. They were not an unqualified success by any means under the conditions I have mentioned, and were eventually discarded after a trial extending over about twelve months because they did not reduce the coal bill—which was the main point.

Dr. Woolf, I believe, enquired at the July meeting regarding the effect, if any, of the gases upon the boiler tubes, and in that connection it may be interesting to refer to a case of rapid deterioration of boiler tubes in this district from the action of coke-oven gas. On investigating the conditions it was found that the presence of a comparatively high percentage of sulphur in the gas was responsible. A gas purification plant was installed and the trouble eliminated. Coke-oven gases are often high in sulphur, and it would be interesting to know if 'Bonecourt' boiler tubes have suffered from its action.

On p. 304 of the paper a waste gas temperature leaving the heater or economiser of 203° F. is given. In reducing to such a low temperature, have the heaters suffered from con-

densation of the gases and the resulting formation of sulphuric acid? I have experienced this in connection with economisers working in conjunction with coal-fired boilers where the terminal gas temperature has been as high as 350° F. Therefore I am inclined to think the trouble would be more pronounced with a terminal temperature of 203° F. **Mr. W. H. Reynolds.**

The mental picture of a power station equipped with 'Bonecourt' boilers, coke-oven gas fired, on p. 302 is attractive, and where sufficient live coke-oven gas were available it might prove worth experimenting with, but I doubt very much if it would pay the average power company or corporation to instal 'Bonecourt' units and the necessary gas producer plants, etc., for them. The first cost of the plant and all necessary accessories, including coal and ash handling and coal storage, etc., would probably be as high, if not higher, than an equivalent coal-fired boiler plant, and I doubt if the overall efficiency, including the producer plant, etc., would be any better. Further, I submit that the 'Bonecourt' boiler cannot be accepted as a commercial proposition instead of an experiment until it has actually established itself as such by proved continuous and reliable service over long periods.

Mention is made in the paper of the adaptability of the 'Bonecourt' boiler to pulverised fuel. I should like to know how it is intended to deal with the incombustible residue from this class of fuel in this type of boiler.

In offering this criticism I desire to point out that I do not wish to detract in any way from the great credit due to Professor Bone and Mr. McCourt for their valuable work in connection with this system, or to minimise the value to the Institute of Major Gregson's paper.

Replying to Mr. W. H. Reynold's remarks, Major W. Gregson writes as follows :—

I note that Mr. Reynolds is still sceptical over the saneness **Major Gregson.**

Major Gregson.

of the practice of quick steam raising in 'Bonecourt' boilers, and I am afraid he and I approach the subject from two different standpoints: Mr. Reynolds from the experience he has had in connection with marine boilers, whereas I base my assertions on my experience with locomotive boilers; and I venture to submit that the latter type of fire-tube boiler much more nearly approaches the 'Bonecourt' type of boiler than does the Scotch marine boiler. We know that the locomotive boiler can stand rapid steam raising, and coupled to this it must be remembered that in the 'Bonecourt' boiler the peak temperatures are lower than obtain in the locomotive boiler; furthermore, it must also be remembered that 'Bonecourt' boilers are in daily work in all classes of industrial establishments, and no trouble whatsoever has resulted from rapid steam raising.

I concur in Mr. Reynolds' statement that I am a 'Bonecourt' enthusiast—i.e. I am strongly in favour of installing 'Bonecourt' units for the propositions for which they are designed, i.e. for gas or oil firing and for the utilisation of waste heat. On the other hand, the fact that I personally am connected with a firm which also manufactures and markets a very excellent water-tube boiler (over which I am *equally* enthusiastic for direct coal firing) will perhaps show that I have hardly become a fanatic over this subject!

I regret that I did not more fully differentiate between the natural draft vertical boiler illustrated in Fig. 8 of my paper and the particulars given *re* utilisation of waste heat from an open-hearth furnace. The boiler in the above-mentioned illustration is not working on an open-hearth furnace but on a special type of steel furnace (in use by a well-known establishment) where conditions are such that natural draught is applicable, and I completely agree with Mr. Reynolds' statement that in practically all cases of waste heat utilisation from industrial furnaces induced draught is necessary. I might remark that with practically all the waste heat units which the 'Bonecourt'

people have at present under construction or erection induced draught is used. Major Gregson.

I gave in my paper the figure of 2 inches of water-gauge as being standard for a waste-heat boiler with induced draught; this of course applies to the boiler *only*, the draught necessary for the furnace being added on to this—i.e. with an open-hearth furnace taking 2 inches draught for the furnace and flues, the fan would deal with a 4-inch total draught.

Mr. Reynolds refers to the 35-ton furnace cited in my paper; owing to the speed of the gases through the tubes, the size of the boiler is not at all excessive. Taking the case of a plant which is at present being put down on an open-hearth furnace in the Midlands burning 3900 lb. of coal per hour, a twin-drum unit is being installed, each drum being 7 feet 3 inches in diameter. In this particular case the boiler evaporation will be 14,000 lb. of steam per hour from and at 212° F.; and I might point out in this connection that the 'Bonecourt' multi-drum boilers are giving every satisfaction in practice, hence I see no reason why Mr. Reynolds should state that this arrangement is not to be recommended. Incidentally, I might remark that the fan water-gauge in this particular instance is $3\frac{1}{2}$ inches, i.e. $1\frac{1}{2}$ inches for the furnace and flues and 2 inches for the boiler, and that the size of the boiler might be considerably reduced in this and similar cases by simply increasing the water-gauge and of course putting in a larger fan unit. This materially reduces first cost, but, on the other hand, owing to the larger size of the fan, somewhat increases the running costs, as the fan naturally takes more power. Of course special arrangements are made in multi-drum units to allow freedom for differential expansion, and in the case of twin-drum boilers where one drum is superimposed on the other a rigid connection is only made at one point, the other end of the upper drum running on a roller bearing accommodated on the lower drum.

Major Gregson.

The question of the spiral retarders is invariably brought up to me by all marine and ex-marine engineers, and I quite concur in Mr. Reynolds' statement regarding the effect, or rather the absence of effect, of spirals on the coal bill of the return-tube type coal-fired multi-tubular boiler. Spirals, under these circumstances, do not reduce the coal bill, but on the other hand they give constant trouble through sooting up; by the time the hot gases reach the spirals in the return tubes of a marine boiler they are not alight, hence all that happens is that unburnt soot settles on the spirals, the suction being insufficient to keep the soot in suspension in the gases, and the layer of soot prevents the spirals from being of much use as extractors of sensible heat from the waste gases. As explained in my paper, the spiral is only of use in combination with induced draught, and in the case of gas-fired boilers with proper mixtures in order to admit of accelerated combustion, and in dealing with the sensible heat of waste gases a high velocity must be kept up to prevent sooting on the spirals. As previously explained, in dealing with products from furnaces using coal or dirty producer gas the spirals are eliminated entirely from the tubes of waste-heat boilers, the efficiency of the boiler being kept up by properly proportioning the heating surface to the volume of gases, the draught, and the temperature range. Naturally in the case of gas-fired boilers the portion of the spiral in the combustion zone gives no trouble whatsoever from sooting, as the incandescent surface burns up any combustible matter and any dry incombustible residue is carried through by the draught.

Regarding the question of tube and economiser corrosion when the gases contain sulphur; as I mentioned at the Swansea meeting tube corrosion occurs during the 'sweating' period when steam is being raised, and the rapid heating-up of the entire heating surface—i.e. the walls of the tubes—and the short period which elapses between lighting up and steam

raising appear to have eliminated tube corrosion entirely in this class of boiler. No trouble whatsoever has been experienced, and I have seen 'Bonecourt' boilers working on some fairly filthy types of gas ; the fact that boilers of other types working alongside the 'Bonecourt' units have suffered from this defect further proves the point. Major Gregson.

The safe outlet temperature is simply a question of being safely above the critical temperature ; in the test quoted in my paper the gas was clean and practically free from sulphur, hence the low temperature was quite satisfactory ; on the other hand, with certain cases of unclean gas (particularly some producer gas) it has been found on previously experimenting with the gases that higher outlet temperatures were necessary. It all depends on the nature of the gaseous fuel or of the waste products, as the case may be. Certain gases are quite safe at very low outlet temperatures, whereas other gases need a much higher temperature in order to eliminate corrosion troubles.

Regarding the adaptability of the 'Bonecourt' boiler for pulverised fuel ; a boiler similar to the oil-fired boiler illustrated in Plate V is under construction for this purpose ; it is being provided with special hopper arrangement for disposing of incombustible residue.

I note that Mr. Reynolds states that the 'Bonecourt' boiler cannot yet be accepted as a commercial proposition instead of an experiment ; the first commercial boiler saw the light of day in 1911 and the newest types of boilers, i.e. those embodying all the improvements described in my paper, are post 1916, but the fact that a large number of 'Bonecourt' boilers are now in constant use in works of all descriptions, ranging from small factories to public and corporation works, and that everywhere they give universal satisfaction, is surely sufficient evidence to allow me to assert that the boiler is now a real commercial proposition. I heartily agree with Mr.

Major Gregson.

Reynolds that great credit is due both to Professor Bone and to the late Lieut. C. D. McCourt for their valuable work in connection with the early development of the principle of gas firing in tubes ; may I also be allowed to point out that credit for bringing the Bonecourt boiler to its present state of perfection should be given to my colleague, Mr. P. St. G. Kirke, to whose untiring zeal the great advances in the type of boiler under review, which have helped so much the development of efficient and cheap steam production and particularly the utilisation of waste heat, are almost entirely due.

Finally, I wish to take this opportunity of thanking Mr. Reynolds for his kindly criticism and to assure him that it is very much appreciated ; and I should like at the same time to give my thanks to the other Members of the Institute who have been good enough to speak on my paper and give me the benefit of their experience and advice. May I also extend my thanks to all Members for the kindly way in which my paper was received and discussed ?

The President.

The President, in closing the discussion, said he had no doubt that they now knew far more concerning the 'Bonecourt' boiler than they did before the paper was read. He had much pleasure in tendering their best thanks to Major Gregson. (Applause.)

The President.

The President said he could not prolong the meeting further that day, and announced that the discussions on the papers ' Mining Warfare ' and ' Notes on an Outburst of Gas and Dust at the Ponthenry Colliery ' would have to be postponed until a later date. In doing so he apologised to Captain D. Ivor Evans, M.C., and Mr. George Roblings, the respective authors, and expressed the hope that they would be able to attend again, because the papers were most important, and especially that of Mr. Roblings.

On the motion of Dr. Jordan a vote of thanks was accorded to the President, and the proceedings then terminated.

# PROCEEDINGS.

## Special Meeting of the Institute held at Cardiff on December 16, 1920.

A SPECIAL meeting of the South Wales Institute of Engineers was held at the Institution, Cardiff, on Thursday, December 16, 1920. Mr. J. Dyer Lewis, the President, being in the chair.

### THE LATE MR. S. W. ALLEN.

The SECRETARY read the following letter from the widow of Mr. S. W. Allen :— **The Secretary.**

14 WORDSWORTH AVENUE, CARDIFF.
*October* 19, 1920.

MARTIN PRICE, ESQ.

DEAR SIR,—Will you please convey to the President and members of the South Wales Institute of Engineers the grateful appreciation of myself and family for their very kind resolution of sympathy, which you have been good enough to send me.

It is a consolation to us to know that my husband's services to the Institute are still remembered by members of the profession to which he was proud to belong, and it was one of his greatest regrets in latter years that he was unable to take a more active part in its affairs.

Please accept our sincere thanks for your personal sympathy,

Believe me,
Yours very truly,
FRANCES C. ALLEN.

## The Application of Cementation to Mining.

BY H. STANDISH BALL, O.B.E., M.SC., A.I.M.M.

In submitting his paper, Major Ball exhibited a series of lantern slides illustrating the subject, explaining each of them.

# THE APPLICATION OF CEMENTATION TO MINING.

By H. Standish Ball, O.B.E., M.Sc., Assoc.I.M.M.

# LIST OF ILLUSTRATIONS.

No. 2. Vol. 36 (2 m)

*Frontispiece.*—Specimen of New Red Sandstone treated by Cementation.

# THE APPLICATION OF CEMENTATION TO MINING.

By H. Standish Ball, O.B.E., M.Sc.. Assoc.I.M.M.

During the last few years cementation has been figuring more and more prominently in mining operations, and the object of this paper is to endeavour to give to the Members of the Institute a general idea of the various phases of mining in which cementation can be used with advantage.

The subject will be treated under the following headings :

1. Historical Introduction and General Description.
2. Drifting in Fissured Ground.
3. Sinking in Fissured Ground.
4. Sinking in Porous Ground.
5. Repairing of Pits in the Lens Coal-fields.
6. General Mining Work :
    (*a*) Drying of Shafts.
    (*b*) Underground Dams.
    (*c*) Underground Fires.
7. Miscellaneous.

## 1. Historical Introduction and General Description.

The benefit of using cement as a means of sealing off water in engineering operations was recognised on the Continent many years ago.

The first example on record was in the year 1864, when a break in the brick-work lining at a depth of 90 yards in one

of the Rhein-Preussen pits near Homburg was sealed by milk of cement being run in from the surface with the aid of a small hand pump. About the same time Monsieur Portier adopted the method in France for repairing breaks in shaft linings.

Plate No. 1 is descriptive of the Portier system, and is of interest when compared with modern practice.

Numerous attempts were made during the next thirty years to improve the process, the general method in sinking being to put down bore-holes outside the perimeter of the shaft for purposes of injection.

This method suffered from many disadvantages, and cementation was not recognised as an important asset in mining until the year 1896, when Monsieur François proved that it was possible to bore and inject from the inside of the shaft below the permanent water-level.

The François cementation process rapidly attained fame on the Continent, and many sinkings were put down by its use in France, Belgium, and Germany.

The process was first introduced in England in 1911, and curiously enough the serious set-back which it immediately encountered ultimately led to its greatest success.

The first sinking essayed was in the New Red Sandstone district of Yorkshire, the sandstone being of a porous nature readily permeable to water. On endeavouring to treat this ground it was discovered that it was difficult to inject any cement at all and impossible to introduce sufficient to produce the desired effect. A specimen of the ground was consequently taken and experiments made with various chemicals to discover a compound which would render the ground more tractable to treatment.

After much patient investigation success was attained, and by means of the François cementation and silicatisation process the sinking was carried out.

At the present time cementation is being successfully

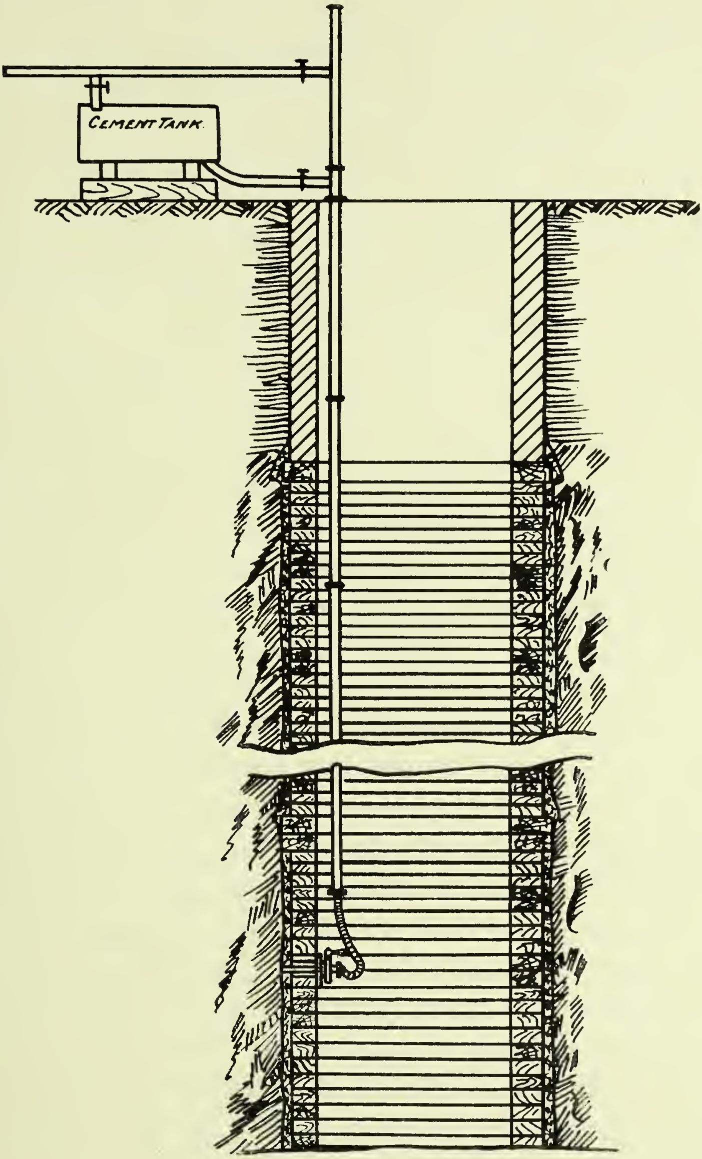



PLATE 1.—ORIGINAL PORTIER CEMENTATION PLANT.

adopted in various parts of the world in both civil and mining engineering work.

*General Description.*—It is a well-known fact that cement emulsion sets under water very slowly, but when subjected to a high pressure, in a comparatively few hours.

When injected into fissures at high pressures successive layers of cement are deposited, the excess water being squeezed out. As more solution is injected the pressure gradually rises owing to the water having to be squeezed through a greater thickness of cement filter. Ultimately the fissure is completely filled with cement with just sufficient water to produce the best conditions for good and quick setting.

This fact was not fully recognised in the early days of cementation, and cement grout was run in by the aid of gravity only and later by means of a hand pump. At the present day specially constructed pumps, capable of exerting a pressure up to 4000 lb. per square inch are used, high pressures being necessary to overcome the pressure of the water in the larger fissures, and to ensure that the cement is in direct contact with the ground in even the smaller ones.

Before describing specific cases of cementation the following general description of the sinking of a shaft will be of interest.

The shaft is sunk by ordinary methods until the presence of water is indicated by means of bore-holes. A number of holes are then bored in the shaft bottom, pipes being cemented in them, their number, position and inclination being dependent upon the size of the shaft and the character of the strata.

Through these pipes bore-holes are sunk by means of a diamond drill. On the tapping of a feeder by one of the holes, boring is immediately stopped and the pipe in the hole connected by means of a length of high pressure flexible hose to a column of pipes in the shaft, leading in turn to the cement pump and mixing tank on the surface.

Fine cement pulp is injected into the hole, the percentage of cement and pressure necessary increasing as the injection approaches completion.

The decision of the final point is purely a matter of experience, and no hard and fast rule can be laid down.

The cement is allowed to set for a few hours and the hole cleaned out; should the fissure be incompletely blocked it is subjected to a second injection. The hole is further deepened by boring until more water is met with, when cementation again takes place. This process is repeated with the various holes, boring and injecting of different holes taking place simultaneously. The ground is treated in this manner until the desired 'length' of ground has been rendered sufficiently water-tight to allow mining and walling operations to proceed, care being taken that a plug of treated ground exists between the bottom of the 'walling' and the top of the new ground to be injected.

The ground is excavated in the ordinary manner and reinforced concrete walling built up, any water not sealed off by the cementation of the bore-holes being shut off by cement injections between the completed lining and the ground.

On the walling being completed a second length of ground is cemented, excavated, and walled, this procedure being repeated until the watery strata has been passed through.

In addition to sinking, cementation can be applied with success to the solution of a number of underground problems, notably the 'drying of shafts,' the extinguishing of fires, and the construction of dams.

A more detailed description of the miscellaneous work for which the process is suitable will be given later.

### 2. Drifting in Fissured Ground.

Before a definite programme of injection can be decided on, all possible information must be obtained from geological sections and test holes.

In the example chosen for description a 12 ft. by 6 ft. drift was being sunk by a colliery at a dip of 23° for the purpose

of working a seam of coal existing at some considerable distance below the bottom of the shaft. Shortly after commencing water was tapped in large quantities in the Pennant Rock, many faults and fissures being proved, rendering drifting difficult and the question of pumping cost one worthy of serious consideration. It was therefore decided to continue drifting by means of cementation.

The general procedure adopted may be divided into two distinct stages :

(*a*) Cementation.
(*b*) Drifting.

(*a*) *Cementation.*—From the information obtained it was decided to 'drift' in lengths of 25 yards, and a description of the cementation of one such 'length' is more or less typical of all.

A 'test' hole was first bored for a distance of 80 to 100 ft. to give a rough estimate of the amount of water likely to be met with, each fissure being treated by injection.

Eleven holes were next bored in the face to a depth of 5 ft., and 2-ins. diameter pipes cemented in, the position and dip of these holes being so chosen as to ensure every fissure in the neighbourhood of the drift being sealed up. For this reason holes 1 to 4 were called the 'bottom holes,' being bored at a dip of approximately 45°, holes 9 and 10 the 'middle holes' with a dip the same as the 'drift,' and holes 5 to 8 the 'top holes' with a dip considerably less. Hole No. 11 was known as the 'test hole' and was the final hole to be treated, it being actually a hole to prove whether the cementation of the 'length' was satisfactory.

The flank holes were inclined slightly outwards to ensure that a 'plug' of treated ground should exist in the neighbourhood of the drift.

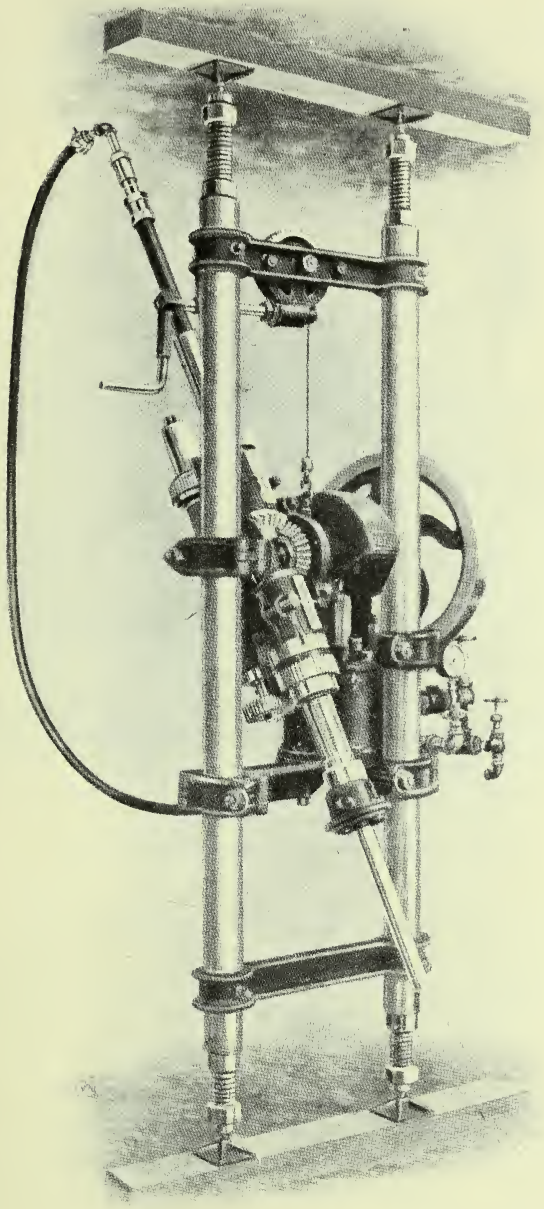


Plate 2.—Sullivan Diamond Drill.

The dip of the holes was in every case varied slightly, in order that as much information as possible should be obtained about the existing fissures.

The bottom holes were first bored and injected, followed by the middle flank holes and finally by the 'top holes,' the 'test hole' being reserved for the last.

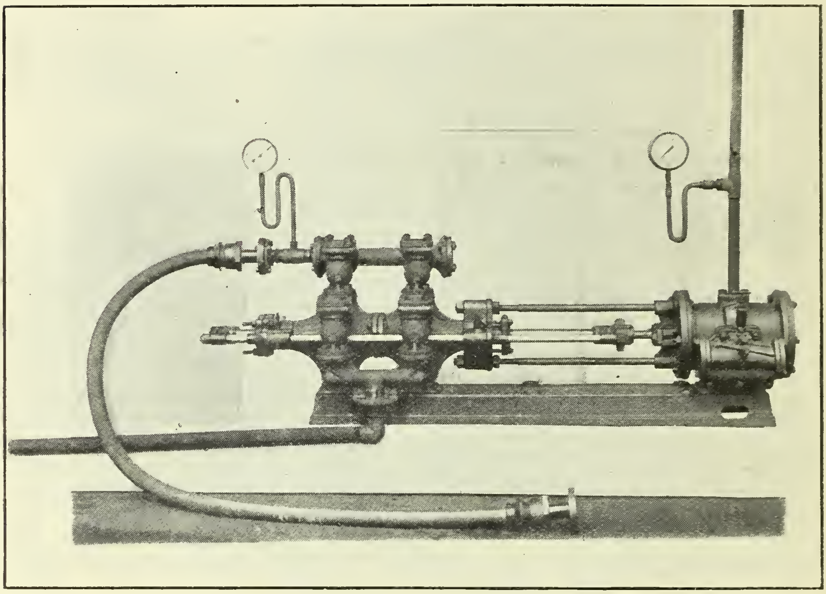


PLATE 3.—HIGH-PRESSURE CEMENTATION PUMP.

The plant used for cementation consisted of a Sullivan diamond drill (Plates 2 and 4), a double-acting high-pressure ram pump (Plate 3), and two cement mixing tanks, with a plentiful supply of water and compressed air at a pressure of 80 lb. per sq. inch.

In boring in ground of so hard a character as the Pennant Rock it was found necessary to use diamond drilling extensively, the setting of the crown being one of the most important items in the daily routine.

Figs. 1 to 6, Plate 5, show the different stages of crown setting. It will be readily understood that this work can only be done by an expert, the slightest carelessness resulting in the loss of one or more diamonds.

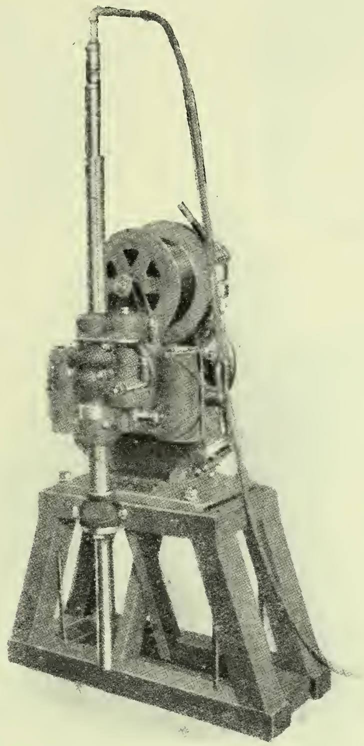


PLATE 4.—SULLIVAN 'BEAUTY' DIAMOND DRILL.

The general procedure in the case of each hole was to bore until the fissure was struck, any sudden rush of water being checked by a cock at the end of the pipe, the cement pump being immediately coupled on by means of a high pressure flexible capable of withstanding a pressure of 4000 lb. per sq. inch, and water followed by cement pulp containing a very small percentage of cement injected. The injection in many cases lasted for several hours, the final point being

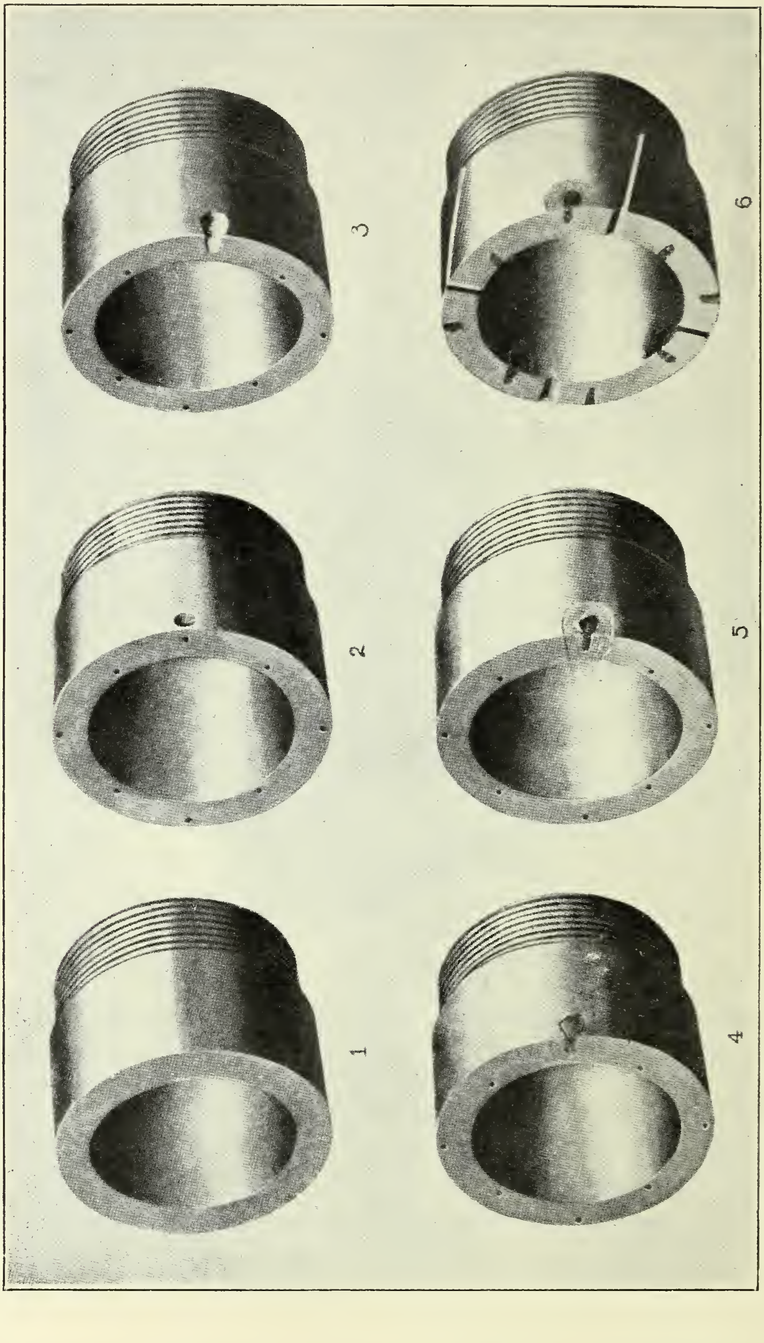



Plate 5.—Setting of a Diamond Crown.

decided largely by the reading of the pressure gauge on the pump and general knowledge of the ground, the percentage of cement being gradually increased before the end.

Before uncoupling, water was injected to clean out the pumping system, and the cement allowed to set for a few hours, while boring proceeded in another hole.

After a period of 8 to 12 hours the cement was cleaned out by 'jumping' with a chisel bit attached to the long boring rods; should the fissure have been satisfactorily sealed off boring was continued until a further fissure was tapped, when injection would again take place.

Plate 7 gives full details of the cementation of the length shown in Plate 6.

It will be seen that approximately 67 per cent. of the total cement was injected into the 'bottom holes,' the ground being of a very broken nature; the injection of these holes greatly assisted the treatment of the others, the cement travelling up the fissures and sealing off a large portion of the water. The holes were carried considerably further than the actual distance of the 'length' itself, it being necessary to have a plug of treated ground as a safeguard when the cementation of a further 'length' should take place.

The summary of work given shows clearly the method of treatment—hole No. 8 may be taken as a typical example.

This hole was bored to a distance of 28 ft., when a feeder of 3 gallons per minute was tapped. Boring was stopped and 3 cwts. of cement were injected until the pressure indicated that cementation was more or less complete; on the hole being cleaned out it was found that a small quantity of water was still being made, necessitating a further injection of 7 cwts.

At a depth of 90 ft. a second feeder amounting to 9 gallons per minute was tapped, and was sealed off by an injection of

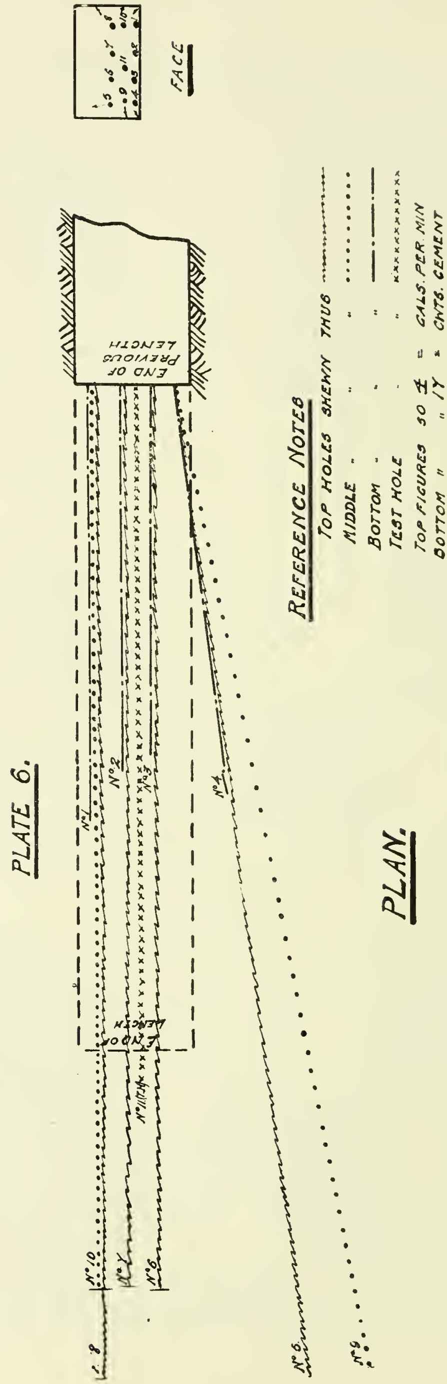


PLATE 6.
FACE
END OF PREVIOUS LENGTH
END OF LENGTH
REFERENCE NOTES
TOP HOLES SHEWN THUS
MIDDLE " "
BOTTOM " "
TEST HOLE "
TOP FIGURES 30 = GALS. PER MIN
BOTTOM " .17 = CWTS. CEMENT
PLAN.
No 1
No 2
No 3
No 4
No 5
No 6
No 9
No 10

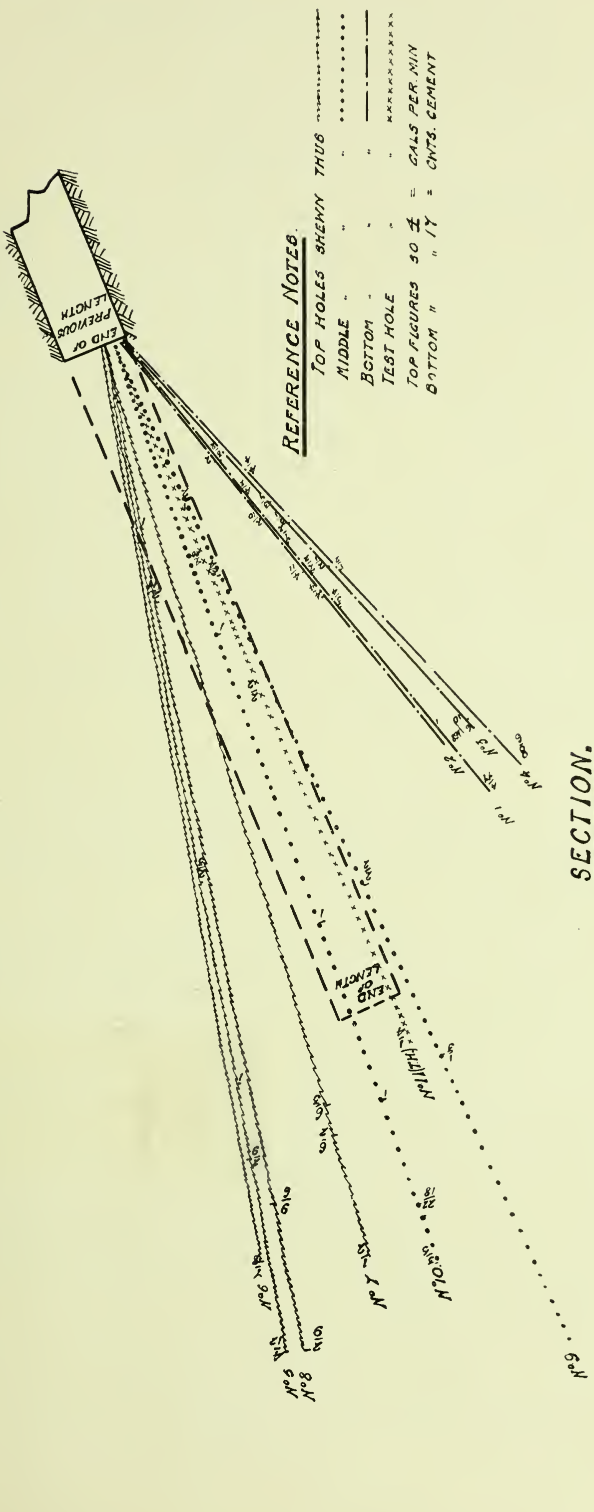



PLATE 6.—DRIFTING IN FISSURED GROUND. CEMENTATION OF A 'LENGTH.'

6 cwts. of cement. The last feeder was met with at 108 ft., requiring an injection of 5 cwts.

On cleaning out, the bore-hole was found to be dry, and was finally sealed up by an injection of 4 cwts.

On the conclusion of the 'drifting' of the particular 'length' under discussion, less than 2 gallons per minute remained of the 160 gallons per minute met with by the bore-holes. This extremely satisfactory result was accomplished by the injection of a total of $19\frac{1}{2}$ tons of cement.

*Drifting.*—Ordinary mining methods were adopted in 'drifting' through the treated ground, the roof being supported by girders resting on brick side walls. As the 'drifting' proceeded many traces of the cement were visible both in fissures and along fault planes, the cement in every case being in the most intimate contact with the surrounding rock.

Drifting by the method described proved to be an unqualified success throughout, the great saving in the cost of pumping being self-apparent.

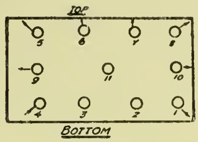
### 3. Sinking in Fissured Ground.

A very large amount of the work accomplished by cementation, particularly on the Continent and in South Africa, comes under this heading.

The principle of working is the same as in the case just described, and consists in sealing off the fissures in the ground by injection before sinking.

Plate No. 8 shows a general example where large fissures were known to exist at a depth of about 300 yards from the surface. Bore-holes were sunk from the sh  bottom radiating outwards to ensure the complete sealing off of every fissure. The length of the bore-holes naturally depended greatly on the character of the ground; in the illustration shown they averaged about 70 yards.

## LE INJECTIONS.




DIP OF DRIFT 23°

**Nº 4** 43° DIP.

| DIST. FT. | WATER GALS/MIN. | CEMENT CWT. | STRATA |
|---|---|---|---|
| 5 | | 4 | ROCK |
| 19 | 4 | - | |
| | | 2 | |
| 33 | 1 | | |
| 63 | 8 | | |
| | | 4 | |
| | | 2 | |
| 63 | 13 | 12 | |

**Nº 5** 10° DIP.

| DATE | DIST. FT. | WATER GALS/MIN | CEMENT CWTS. | STRATA |
|---|---|---|---|---|
| JULY 24 | 23 | | | ROCK |
| 26 | 58 | 2 | 3 | - |
| 27 | 90 | 3 | | - |
| 28 | | | 6 | - |
| - | | | 3 | - |
| AUG.T 5 | 109 | 4 | 3 | - |
| 6 | | | 2 | - |
| 11 | | | 7 | - |
| | 109 | 9 | 24 | |

**Nº 6** 9° DIP.

| DATE | DIST FT. | WATER GALS/MIN. | CEMENT CWT. | STRATA. |
|---|---|---|---|---|
| AUG.T 7 | 42 | 1 | | ROCK |
| 10 | 99 | 1 | | . |
| 11 | | | 5 | . |
| 13 | | | 3 | - |
| | | | | - |
| | 99 | 2 | 8 | |

**Nº 10** 19° DIP.

| | | | |
|---|---|---|---|
| 25 | 4 | | ROCK |
| - | | 20 | |
| 40 | - | | . |
| 65 | 2 | | |
| 85 | 1 | | . |
| 98 | 22 | 18 | - |
| 103 | 3 | 3 | . |
| | | 2 | - |
| 111 | 32 | 43 | |

**Nº 11** 25° DIP (TEST HOLE)

| | | | | |
|---|---|---|---|---|
| AUG.T 14 | 13 | | | ROCK |
| | 40 | 2 | 2 | |
| 16 | 58 | 1 | | |
| 17 | 68 | | | |
| | 75 | | | |
| 18 | 80 | | 4 | |
| | 80 | 3 | 6 | |

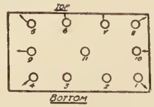
**SUMMARY**

| HOLE | DIST. | GALS/MIN | CEMENT CWTS | ORDER OF TREATMENT |
|---|---|---|---|---|
| Nº 1 | 62 | 24 | 59 | 4 |
| " 2 | 55 | 12 | 25 | 2 |
| " 3 | 56 | 28 | 162 | 1 |
| " 4 | 63 | 13 | 12 | 3 |
| 5 | 109 | 9 | 24 | 7 |
| " 6 | 99 | 2 | 8 | 9 |
| " 7 | 100 | 13 | 7 | 10 |
| " 8 | 108 | 14 | 28 | 8 |
| 9 | 118 | 10 | 14 | 5 |
| 10 | 111 | 32 | 43 | 6 |
| 11 | 80 | 3 | 6 | 11 |
| | 961 | 160 | 386 | |

. Summary of Bore-hole Results.

To face p. 530

## SUMMARY OF BORE-HOLE INJECTIONS.




DIP OF DRIFT 23°

### No. 1 39° DIP

| DATE | DIST. FT. | WATER GALS/MIN | CEMENT CWT. | STRATA |
|---|---|---|---|---|
| JUNE 26 | 10 | · | - | ROCK |
| 29 | 16 | 3 | 2 | · |
| 30 | 21 | 4 | · | · |
| JULY 1 | · | · | 2 | · |
| 2 | 28 | 7 | 2 | BROKEN GROUND |
| 3 | 32 | 2 | 2 | · |
| 6 | 37 | 3 | 4 | · |
| 8 | 53 | 1 | · | · |
| 8 | 62 | 4 | 5 | · |
| 9 | · | | 44 | · |
| TOTAL | 62 | 24 | 59 | |

### No. 2 39° DIP

| DATE | DIST FT. | WATER GALS/MIN | CEMENT CWT. | STRATA |
|---|---|---|---|---|
| JUNE 21 | 27 | 4 | | ROCK |
| 22 | | | 10 | ROCK |
| 23 | 32 | 4 | | · |
| 24 | - | - | 11 | · |
| 25 | 35 | 4 | | · |
| 26 | | | 4 | |
| 30 | 55 | | | |
| TOTAL | 55 | 12 | 25 | |

### No. 3 42° DIP

| DATE | DIST. FT. | WATER GALS/MIN | CEMENT CWT. | STRATA |
|---|---|---|---|---|
| JUNE 23 | 19 | 4 | 1 | ROCK |
| 24 | 24 | 3 | 1 | · |
| 25 | 27 | 3 | 1 | · |
| 25 | 55 | 12 | - | · |
| 26 | 56 | 6 | 1 | VERY FISSURED GROUND |
| 26 | | | 16 | |
| 28 | | | 20 | |
| 30 | | | 10 | |
| JULY 1 | | | 12 | |
| 3 | | | 16 | |
| 5 | | | 26 | |
| 9 | | | 8 | |
| 12 | | | 19 | |
| 13 | | | 4 | |
| 14 | | | 12 | |
| 22 | | | 6 | |
| 23 | | | 9 | |
| TOTAL | 56 | 28 | 162 | |

### No. 4 43° DIP

| DATE | DIST FT. | WATER GALS/MIN | CEMENT CWT. | STRATA |
|---|---|---|---|---|
| JUNE 22 | 5 | | 4 | ROCK |
| JULY 2 | 19 | 4 | - | |
| 5 | | | 2 | |
| 6 | 33 | 1 | | |
| 7 | 63 | 8 | | |
| 8 | | | 4 | |
| 9 | | | 2 | |
| TOTAL | 63 | 13 | 12 | |

### No. 5 10° DIP

| DATE | DIST. FT. | WATER GALS/MIN | CEMENT CWTS | STRATA |
|---|---|---|---|---|
| JULY 24 | 23 | | | ROCK |
| 26 | 58 | 2 | 3 | - |
| 27 | 90 | 3 | | - |
| 28 | | | 6 | - |
| - | | | 3 | - |
| AUGT 5 | 109 | 4 | 3 | - |
| 6 | | | 2 | · |
| 11 | · | | 7 | · |
| TOTAL | 109 | 9 | 24 | |

### No. 6 9° DIP

| DATE | DIST FT | WATER GALS/MIN | CEMENT CWT | STRATA |
|---|---|---|---|---|
| AUGT. 7 | 42 | 1 | | ROCK |
| 10 | 99 | 1 | | · |
| 11 | | | 5 | · |
| 13 | | | 3 | · |
| | | | | - |
| TOTAL | 99 | 2 | 8 | |

### No. 7 16° DIP

| | | | | |
|---|---|---|---|---|
| AUGT 12 | 20 | | | ROCK |
| 13 | 86 | 6 | 3 | - |
| 14 | 88 | 6 | | - |
| 16 | | | 2 | - |
| 17 | 100 | 1 | | · |
| 18 | | | 2 | - |
| TOTAL | 100 | 13 | 7 | |

### No. 8 11° DIP.

| | | | | |
|---|---|---|---|---|
| JULY 26 | 28 | 3 | 4 | ROCK |
| 27 | · | · | 7 | · |
| 29 | 95 | 9 | | · |
| 30 | | | 6 | - |
| AUGT. 5 | 98 | | | - |
| 6 | 108 | 2 | 5 | · |
| 10 | | | 4 | |
| TOTAL | 108 | 14 | 26 | |

### No. 9 24° DIP

| | | | | |
|---|---|---|---|---|
| JULY 9 | 19 | 2 | 2 | ROCK |
| 10 | 27 | 2 | 1 | |
| 13 | · | 2 | 3 | · |
| 15 | · | 3 | 2 | · |
| 19 | · | · | 3 | · |
| 23 | 118 | 1 | - | - |
| 24 | | | 3 | - |
| TOTAL | 118 | 10 | 14 | |

### No. 10 19° DIP.

| | | | | |
|---|---|---|---|---|
| JULY 15 | 25 | 4 | | ROCK |
| 16 | - | | 20 | |
| 19 | 40 | - | | · |
| | 65 | 2 | | |
| 21 | 85 | 1 | | · |
| · | 98 | 22 | 18 | · |
| 23 | 103 | 3 | 3 | - |
| - | | | 2 | - |
| TOTAL | 111 | 32 | 43 | |

### No. 11 23° DIP (TEST HOLE)

| | | | | |
|---|---|---|---|---|
| AUGT. 14 | 13 | | | ROCK |
| | 40 | 2 | 2 | |
| 16 | 58 | 1 | | |
| 17 | 68 | | | |
| | 75 | | | |
| 18 | 80 | | 4 | |
| TOTAL | 80 | 3 | 6 | |

### SUMMARY

| HOLE | DIST. | GALS/MIN | CEMENT CWTS | ORDER OF TREATMENT |
|---|---|---|---|---|
| No. 1 | 62 | 24 | 59 | 4 |
| " 2 | 55 | 12 | 25 | 2 |
| " 3 | 56 | 28 | 162 | 1 |
| " 4 | 63 | 13 | 12 | 3 |
| 5 | 109 | 9 | 24 | 7 |
| " 6 | 99 | 2 | 8 | 9 |
| " 7 | 100 | 13 | 7 | 10 |
| " 8 | 108 | 14 | 26 | 8 |
| 9 | 118 | 10 | 14 | 5 |
| 10 | 111 | 32 | 43 | 6 |
| 11 | 80 | 3 | 6 | 11 |
| | 961 | 160 | 386 | |

Plate 7.—Drifting in Fissured Ground. Summary of Bore-hole Results.

*To face p.* 530

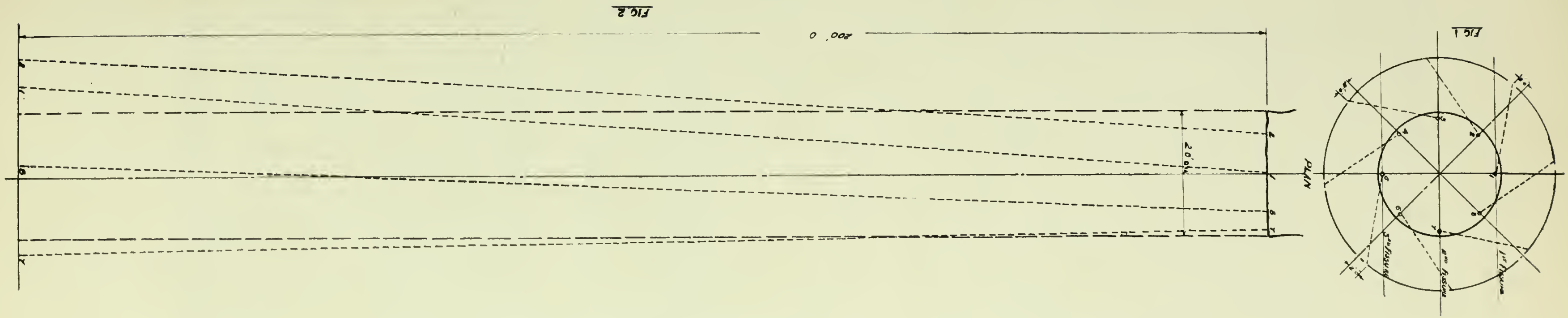



Plate 8.—Arrangement of Holes for Cementation of a Circular Shaft in Fissured Ground.

Plate No. 9 shows a shaft which had been sunk through the Syenite to the Dolomite, a great quantity of water being encountered. In this case it was necessary to insert a concrete plug at the shaft bottom to seal off the watery area before cementation could be proceeded with.

In the example chosen for description a 12 ft. diameter shaft had been sunk for a distance of 63 yards without any accurate knowledge of the ground having been previously obtained. Soon after sinking was commenced water was met with in the shales, the quantity rapidly increasing as the sinking proceeded, until matters became so serious that the pumping installation proved totally inadequate to cope with the inrush of water, the shaft being completely flooded in four hours on every occasion the pumping was stopped. Sinking operations were suspended and many plans tried to deal with the situation, on one occasion a diver being despatched down the shaft to plug up the fissures with wooden wedges under a head of 44 yards of water.

It was estimated that several thousand gallons per minute were entering the shaft through the sides and bottom, and as no remedy could be found after pumping operations had been carried on for six months, the sinking was abandoned for some four years.

Owing to the successful application of the François cementation process in this country in so many cases, it was finally decided to apply it to the sinking in question to endeavour once more to reach the coal measures.

The work was divided into the following stages :

(*a*) Insertion of a concrete plug in the shaft bottom.

(*b*) Treatment of shaft sides.

(*c*) Boring through plug and injection of underlying strata.

(*d*) Sinking and walling.

(*e*) Boring of pilot holes in new ground.

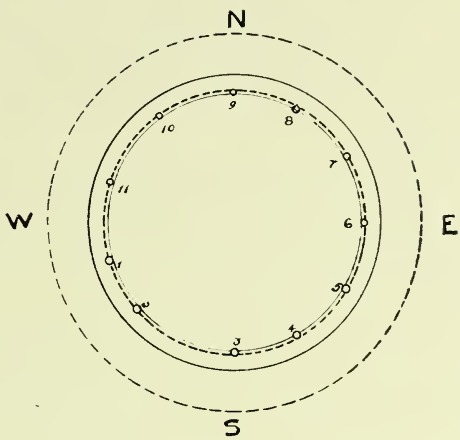



FIG 1

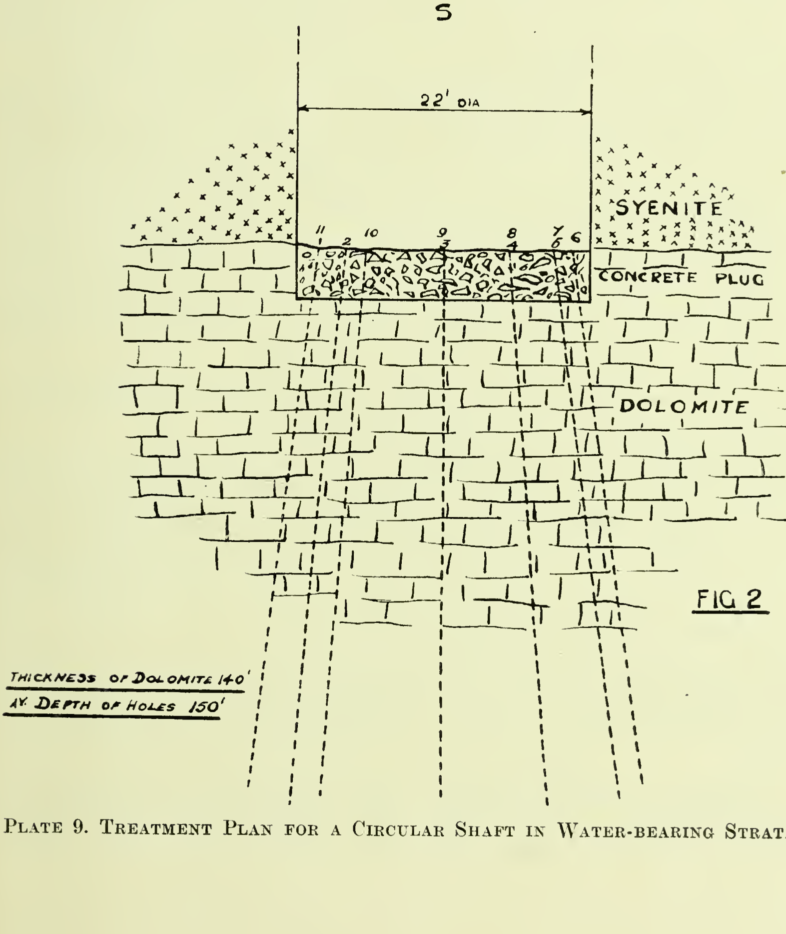



FIG 2

PLATE 9. TREATMENT PLAN FOR A CIRCULAR SHAFT IN WATER-BEARING STRATA.

(*a*) *Insertion of a Concrete Plug in the Shaft Bottom.*—As it was estimated that the majority of the water was being made through a large fissure in the shaft bottom, it was decided to seal this off by means of a concrete plug before the shaft walls were treated.

Without dewatering the shaft, the shaft bottom was cleaned as well as possible, six $1\frac{1}{2}$-in. diameter iron pipes being then suspended inside the shaft, three of them being some 6 inches from the bottom and three about 2 feet.

The last 20 ft. of each length of piping consisted of 3 ins. diameter pipes so as to allow of diamond drilling through them during the treatment of the ground underlying the plug.

About 100 tons of rock were thrown in, care being taken to distribute it evenly, the amount previously having been calculated to form a plug of about 15 ft. in thickness, sufficient to seal off the fissured portion and stand the static pressure.

Cement was injected through the six pipes into the mass of rock, this being continued until signs of cement on top of the plug became evident; 42 tons of cement were injected in this manner, the first two holes receiving the greatest amount, the whole injection only taking 14 hours.

At the conclusion the shaft was allowed to stand for a month to permit the concrete plug to set.

(*b*) *Treatment of Shaft Lining.*—On the dewatering of the shaft it was found that a number of comparatively large feeders existed in the sides above the top of the plug, several of them averaging 50 gallons per minute. Six weeks were spent in treating these by means of 29 bore-holes drilled in the shaft sides to various depths, sawdust and thick cement being used in many cases to form a foundation for blocking up the feeders.

(*c*) *Boring through Plug and Injection of Underlying Measures.*—Before the plug was removed it was found

necessary to bore and inject a further 10 holes through the sides of the plug, several small fissures being proved to be in existence. The pipes through the plug were discovered to be in good order, and there was no difficulty in boring through them and treating some 40 yards of the underlying strata, 142 tons of cement being used during the various injections.

Plate No. 10 shows graphically the progress of one of the bore-holes, giving the distance bored between fissures, the water encountered, the cement used, and the pressure necessary for injection.

The length of the bore-hole was 41 yards; water sealed off 70 gallons per minute; cement used $56\frac{1}{2}$ tons; and the time taken for treatment 6 weeks.

(*d*) *Sinking and Walling.*—On the plug being removed the shaft was found to be practically dry, allowing sinking and walling to proceed in the usual manner without pumps, a 9-in. brick lining being put in.

(*e*) *Boring of Pilot Holes in New Ground.*—Though the watery measures were considered to have been successfully treated and sunk through, it was nevertheless considered expedient to have pilot holes ahead of the sinking to give warning of further fissures.

These were bored accordingly, with satisfactory results, and the coal measures were successfully reached approximately a year after the commencement of the treatment of the ground by cementation, the total water in the shaft being less than 2 gallons per minute.

## 4. Sinking in Porous Ground.

In the many types of ground in which cementation has been used, more difficulties have been met with in the treatment of porous ground than in any other.

As has been previously mentioned, when sinking by

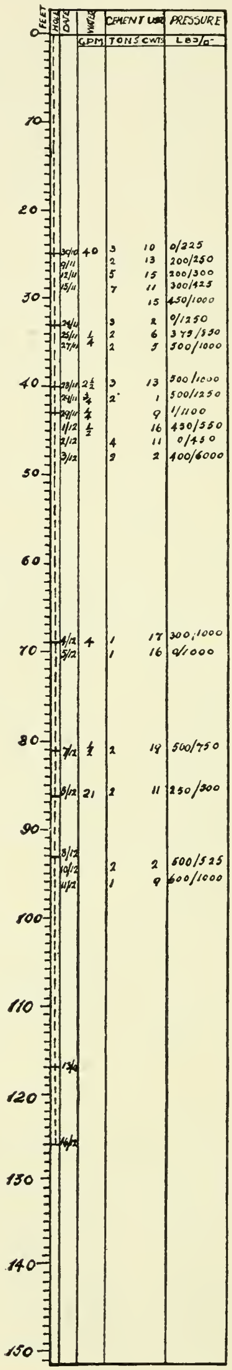



Plate 10.—Sinking in Fissured Ground. Cementation Diagram of a Vertical Bore-hole.

cementation was first essayed in the New Red Sandstone of Yorkshire it was only possible to shut off 50 per cent. of the total water by cement injections. After a certain amount of experimental work had been successfully carried out it was discovered that by injecting solutions of silicate of soda and sulphate of alumina, followed by cement, it was possible to stop 95 per cent. of the total water.

Though it would have been practicable to have stopped the whole amount, it was decided to deal with the remaining water by pumping.

It was found that many of the fissures encountered contained a quantity of loose sand in them, and consequently when cement was injected the sand was forced into the formation of a species of dam, beyond which the cement could not penetrate. The action of the solutions was of a chemical nature, the aluminium silicate formed on their coming in contact with one another performing the duty of a lubricant to the fissure, percolating through the sand and stiffening it to such an extent that cement could be easily injected at less than one-sixth of the pressure previously necessary, the chemical precipitate formed being of a gelatinous nature. In one case before treatment by chemicals it was only found possible to inject some 20 lb. of cement at a pressure of 1000 lb. per sq. inch into a bore-hole ; after 80 gallons of chemical solution had been used, over 20 tons of cement were injected into the same hole at a pressure less than 250 lb. per sq. inch.

The usual method of 'walling' in connection with this treatment is by means of reinforced concrete, and as the two subjects are comparatively new and are constantly being improved upon, they will be dealt with separately in some detail under the headings :

(*a*) Silicatisation and Cementation.

(*b*) Walling with reinforced concrete.

(*a*) *Silicatisation and Cementation.*—It is extremely difficult

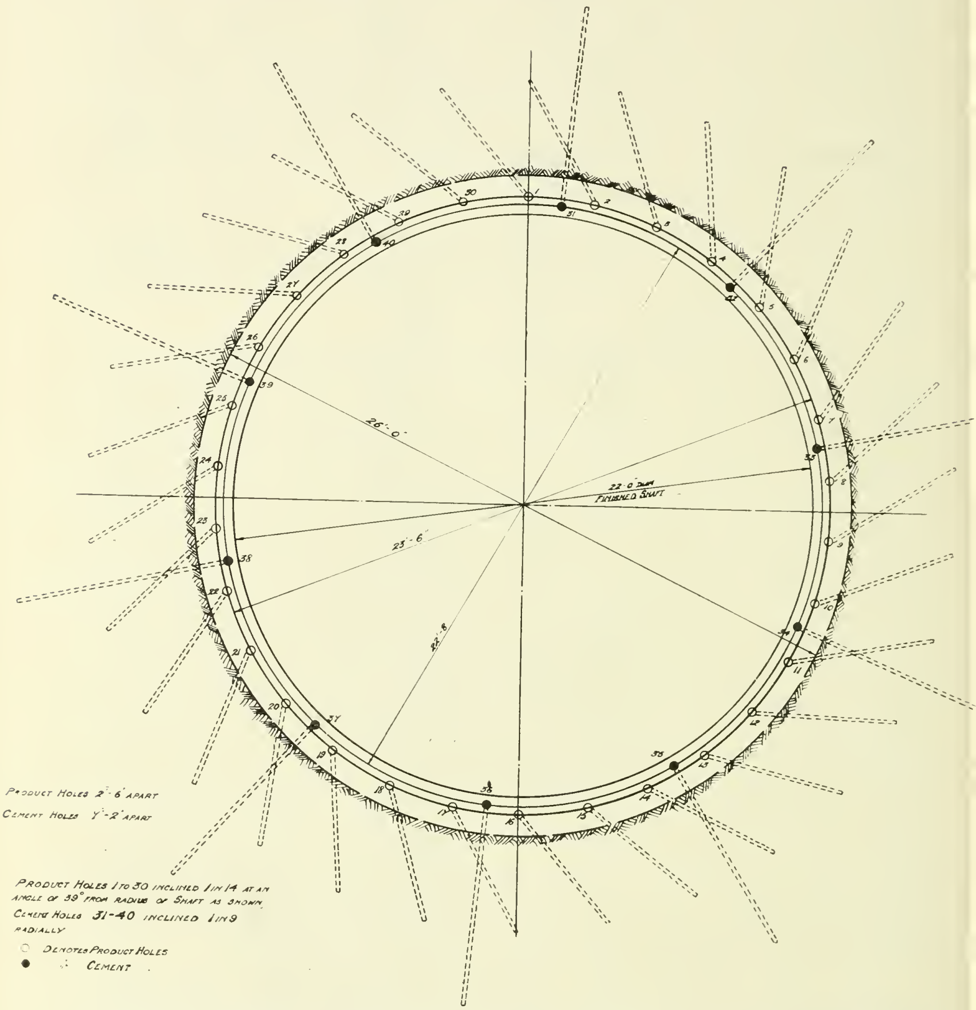



PLATE 11.—GENERAL ARRANGEMENT OF BORE-HOLES FOR SILICATISATION AND CEMENTATION OF A SHAFT IN POROUS WATER-BEARING STRATA.

to lay down any definite programme for treatment by silicatisation, every case having to be treated individually.

Naturally the strength of the chemical solutions and the rate at which they are pumped into the ground are important

factors, and it has been found that the ideal treatment in one case is often unsuitable for another in the same neighbourhood, being due to some slight difference in the geological characteristic of the ground.

Plate No. 11 shows a general plan of product and cement holes for the treatment of a 'length.' The product holes are taken in pairs, being treated in turn with aluminium sulphate and sodium silicate, or *vice versâ*, followed by cement injections. The ground having been well prepared, further cement is injected through the cement holes following the usual cementation procedure. The 'dip' and the 'direction' of the various holes are all carefully planned out according to the local knowledge of the ground treated.

Plate No. 12 shows the plant lay-out necessary for the treatment of two shafts, and is interesting when compared with the plant shown in Plate No. 1.

The sulphate and silicate solutions run from storage vats to the mixing tanks, where they are diluted to the desired 'Twaddell' strength before passing to the pumping circuit. The diagram is self-explanatory, and shows that it is possible to proceed with the injection of the ground in one shaft while the other is being sunk and walled.

The case chosen for description is an example of a shaft 22 ft. in diameter that had experienced many vicissitudes of fortune before cementation was adopted. Commenced eleven years ago, it was sunk to a depth of 158 yards, some two years being taken during the sinking, a very great amount of water having been met with in the Red Sandstone.

Plate No. 13 is a diagrammatic section of the sinking, and gives a very fair idea of the difficulties encountered. Cementation was tried at one period, but owing to silicatisation at that time not being in existence, did not prove a success, being due to the nature of the ground.

Ultimately it was decided to adopt the 'freezing process,' the freezing pipes being sunk to the coal measures by a German

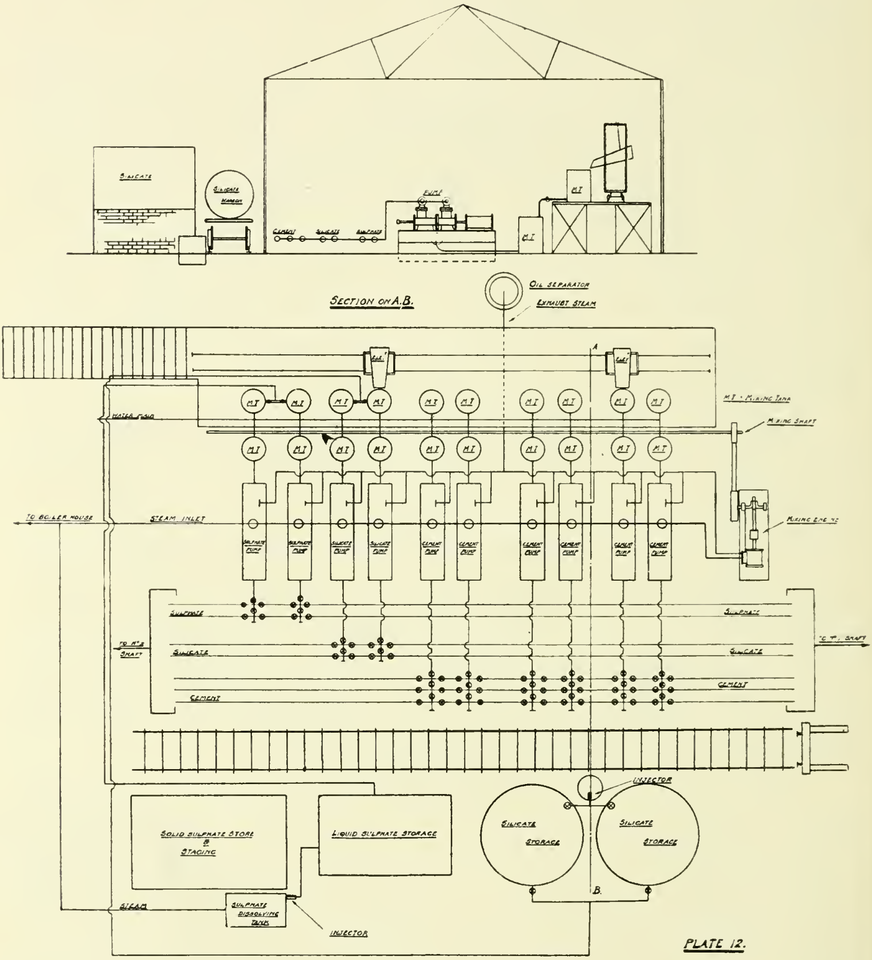



Plate 12.—Diagrammatic Representation of Plant Lay-out for Cementation of Shafts through Water-bearing Strata.

firm just before the outbreak of hostilities. On account of the war, work was once more held up, and was only recommenced last year, it being finally resolved to carry out the sinking by

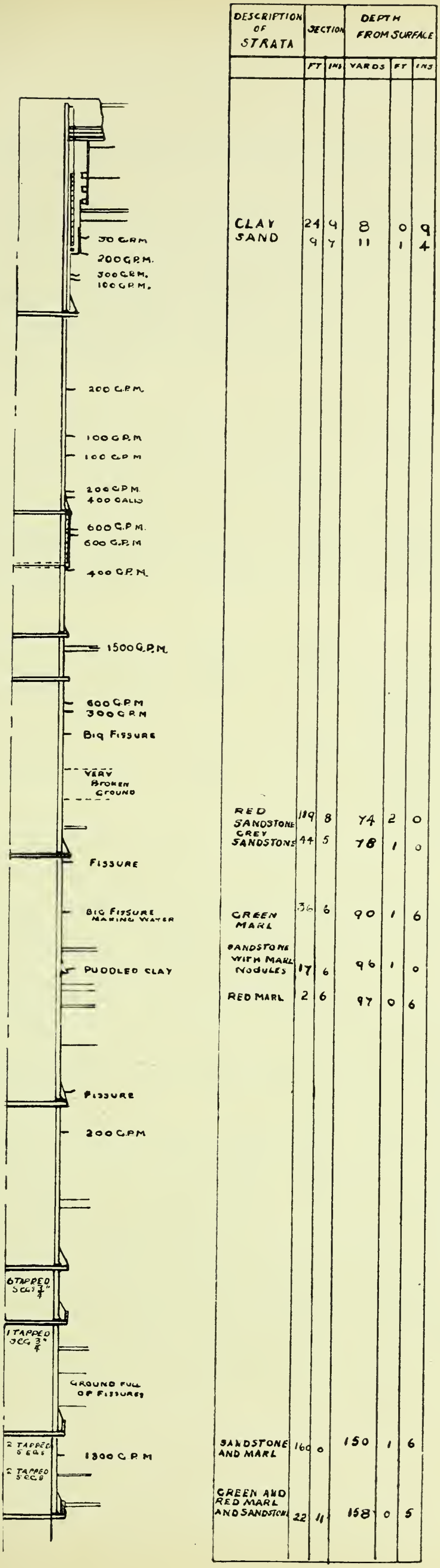



Plate 13.—Geological Section of a Shaft in Porous Ground before Treatment by Cementation.

cementation, a shaft in the neighbourhood having been successfully sunk by this method in ground of a similar nature.

Owing to the extremely fissured and broken nature of the ground in the bottom part of the shaft, a concrete plug had to be placed in position before any cementation could take place.

This was inserted in the manner previously described, the plug in this case being very much larger, being fully 55 ft. in length. Several hundred tons of rock were thrown into the shaft, and a large quantity of cement injected through the pipes previously placed in position, the total injection taking fifty-six hours.

The following is a brief summary of the work that was necessary from the insertion of the plug to the treatment of the underlying strata :

Insertion and cementation of plug.
Setting of plug.
Dewatering and treatment of shaft tubbing.
Boring and injecting of holes through plug.
Excavation of plug and treatment of sides.
Boring and injecting of two series of product holes.

The work was further complicated by the intersection of two of the freezing holes.

Table I., p. 33, gives particulars of the cementation of one of the plug bore-holes.

It will be noticed that the large feeders met with were successfully sealed off with ‘ product ’ and cement injections. The term ‘ product holes ’ was applied to those holes bored specially for the injection of the chemicals, and the treatment of same was of a highly technical character, the strength and amount of various injections having to be very carefully calculated.

Plate No. 14 shows a section of the shaft, giving particulars of injections. It is sufficient to say that as a result of the programme of work just enumerated the water was reduced from an overwhelming amount to a very small quantity indeed.

TABLE I.—CEMENTATION OF GROUND THROUGH PLUG.

*No. 1 Hole.*

| Date. | Boring Depth. Feet. | Total Depth. Feet. | Feeder. Galls/min. | Cement injected. Cwts. | Pressure lb./sq. inch. | Silicate injected. Tanks. | Sulphate injected. Tanks. |
|---|---|---|---|---|---|---|---|
| May 14th | 50 | 50 | Nil | | | | |
| ,, 15th | 15 | 65 | 40 | 10 | 600 | | |
| ,, 17th | 40 | 105 | 165 | | 250/350 | 6 | 6 |
| | | | | 4 | 700 | | |
| | | | | 24 | 1000 | | |
| ,, 19th | 25 | 130 | 88 | — | 250/500 | 20 | 20 |
| | | | | 2 | 800 | | |
| | | | | 10 | 1000 | | |

(*b*) *Walling with Reinforced Concrete.*—Provided that the ground has been previously treated by cementation, this type of lining is rapidly taking the place of cast-iron tubbing.

It can be made practically water-tight and can stand any static pressure met with in practice with a good safety margin.

Several shafts in this country have been lined with ferro-concrete and several more will shortly follow, this type of lining following on naturally after cementation. It is worthy of note that several of the pits in the French coal-fields destroyed by the Germans are to be relined with reinforced concrete in place of the existing wooden tubbing.

Where water has not been entirely excluded by cementation of the measures, it is subsequently shut off by injections between the completed lining and the ground.

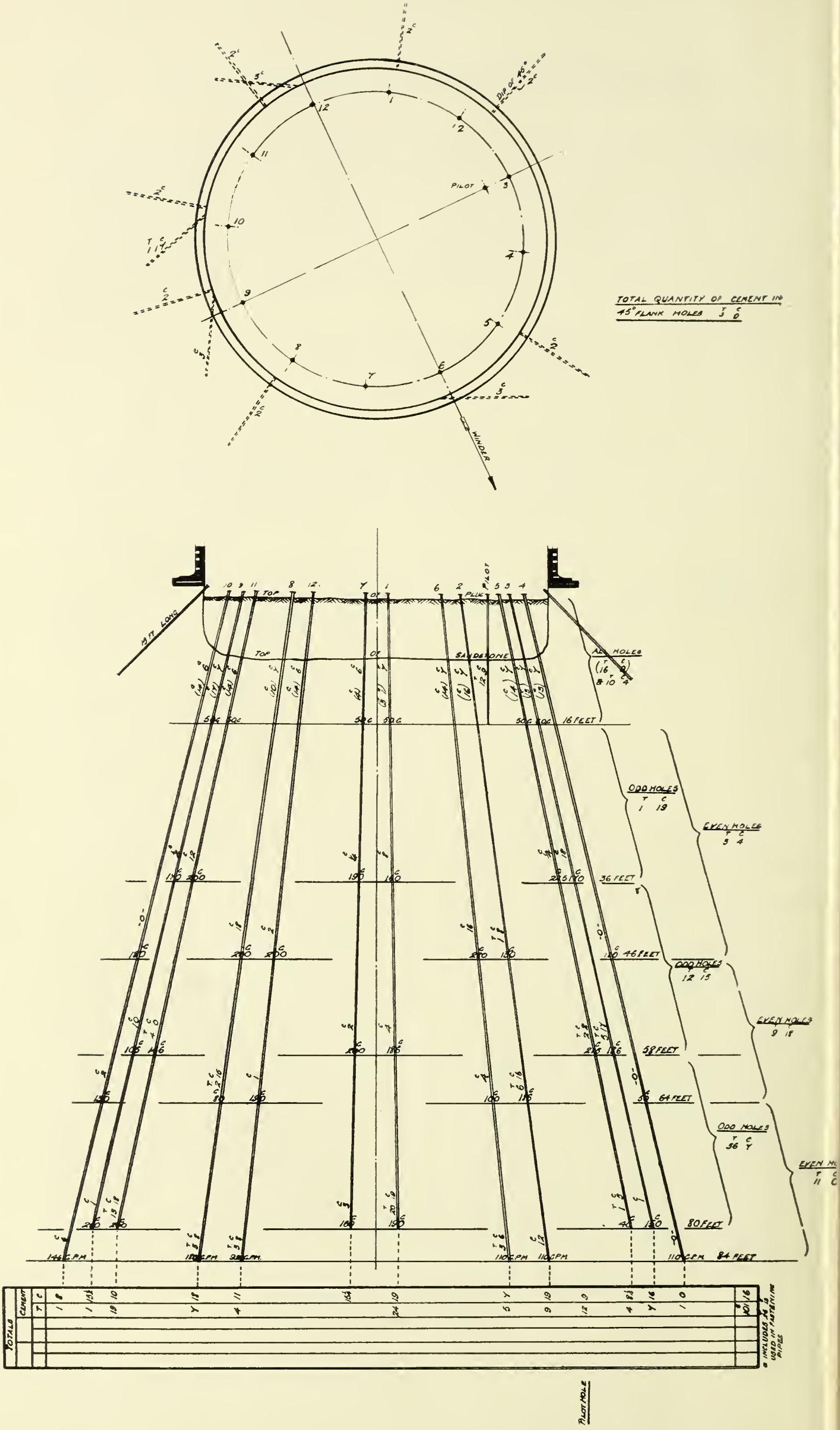



PLATE 14.—SECTION OF A SHAFT 'LENGTH' AFTER TREATMENT BY CEMENTATION.

It will be seen that with the exception of earth movement no pressure can be established on the walling by the water, other than the purely local heads in the fissures themselves.

In the case of a shaft lined with cast-iron tubbing, not only is the full static loading maintained during its whole life, but the lining naturally deteriorates with age and change of temperature.

In certain permeable measures, e.g. New Red Sandstone, cementation is not carried out to the entire exclusion of water for economic reasons; complete security is however assured by designing the walling to meet the increased pressure expected.

Of the two types of lining concrete is decidedly cheaper and far easier to place in position.

Though the design of the ferro-concrete walling is constantly changing in many small details, the main points and principles of inserting it remain the same.

Plate No. 15 gives full details of a more or less standard type, and is practically self-explanatory.

The sides of the shaft having been prepared for the required length and temporarily supported with timber rings and backing boards, a certain number of back plates are put in position, care being taken that the joints of each successive ring are staggered. Two rings of false plates are next carefully centred and erected, the space between the back plates and false plates being filled with concrete mixed on the surface in the required proportions. The backs of the false plates are cleaned and greased to allow of their removal after the setting of the concrete.

Several pipes are left in every ring, these pipes lying horizontally in the concrete, with one end flush against the back plates. When the wall is in position, the plates are pierced and the space between them and the wall treated

by cementation, an intimate contact with the ground thus being established.

Until this process has taken place, the water is drawn off by means of pipes placed around the shaft above the crib and behind the back plate.

The length and thickness of the walling depend largely upon the nature of the ground. Shafts in water-bearing ground have been lined in this manner at depths of 2000 ft. with full static pressure, and there is no reason why this system of lining should not be successfully carried out at greater depths.

### 5. Repairing of Pits in the Lens Coal-Fields.

As a result of the British victory on the Vimy Ridge on April 9, 1917, a large number of the collieries in the neighbourhood of Lens were recaptured from the Germans, and a military engineer was immediately instructed to carry out an investigation and ascertain whether there was an underground communication with Lens, that town being still in hostile hands.

Fosse 11 was the first pit examined within a few days after the German retirement. On reaching the heap of débris representing the surface plant a roaring sound was heard, apparently proceeding from the depths of the shaft. A small party was formed, and after some difficulty succeeded in descending the shaft for a certain distance. The noise was found to be caused by a cavity in the tubbing some sixteen feet square, through which the water was pouring at the rate of many thousand gallons a minute, the break occurring about sixty yards from the surface, and being some distance below the permanent chalk water-level. Traces of German handiwork were apparent, being represented by a kibble used by their demolition party, electric leads, etc.

So rapidly were the workings of the mine flooded that, in

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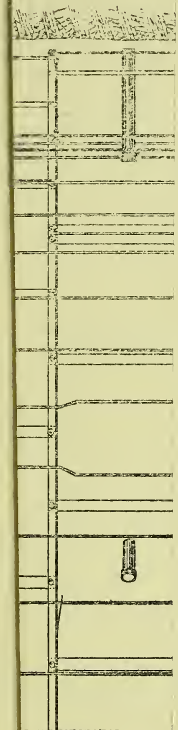
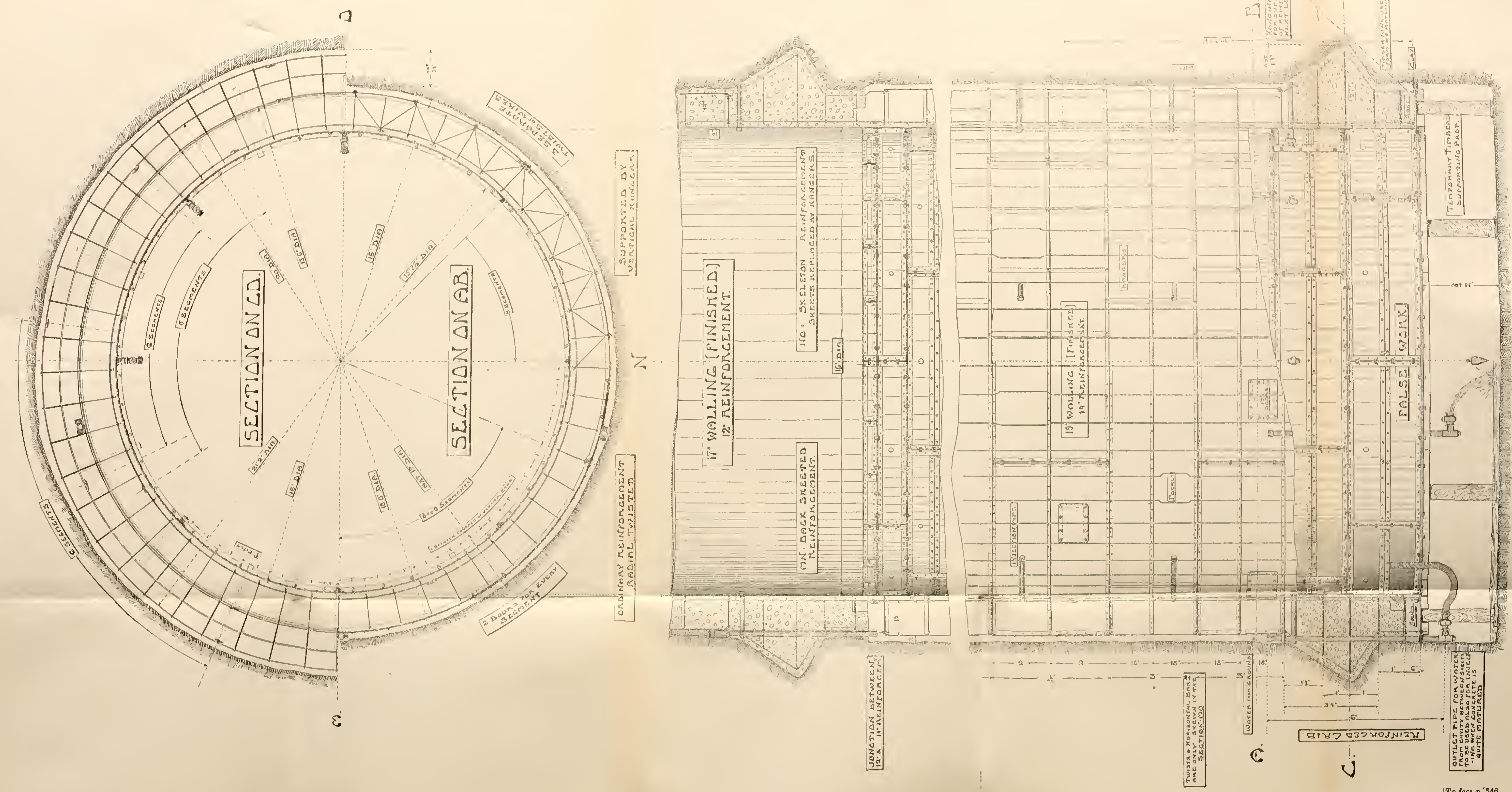


PLATE 15.

# SHAFT LINING OF REINFORCED CONCRETE.

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spite of the shaft being some 340 yards deep, the water rose to the chalk water-level within the space of a few days.

On measuring the water-level in several other pits the rise was found to be constant, proving that all the eighteen pits of the Concession de Lens were flooded; it was therefore thought probable that other shafts had been treated in a similar manner to the one mentioned.

This was found to be the case, and negotiations were immediately entered into by the French Government with various English firms to supply pumping machinery for the dewatering of these pits when once the breaks had been sealed off.

Soon after the conclusion of hostilities Monsieur François was entrusted with the work of repairing several of the shafts. By means of suitably placed bore-holes and injections of cement under high pressure the water flowing into these shafts was sealed off in a comparatively short time, and the ultimate recovery of the coal greatly expedited.

The procedure adopted in the cementation of each pit differs little in detail; it is therefore only proposed to deal with pit No. 11.

When the pit was originally sunk, a very large horizontal fissure was encountered at a depth of 63 yards, a certain amount of difficulty being experienced in dealing with the great amount of water. This fact was taken advantage of by the Germans, for a charge was exploded in the shaft at the exact depth of the fissure, causing holes 16 ft. by 22 ft. and 19 ft. by 13 ft. to be blown in the sides. The resulting rush of water has been already mentioned, and it was this break in the tubbing and consequent flooding of the mine that had to be dealt with by cementation.

Plate No. 16 shows a section of the shaft, giving particulars

of the shaft lining, ground, and position where the tubbing was blown out by explosion, the lower charge having been exploded previously without any very serious result.

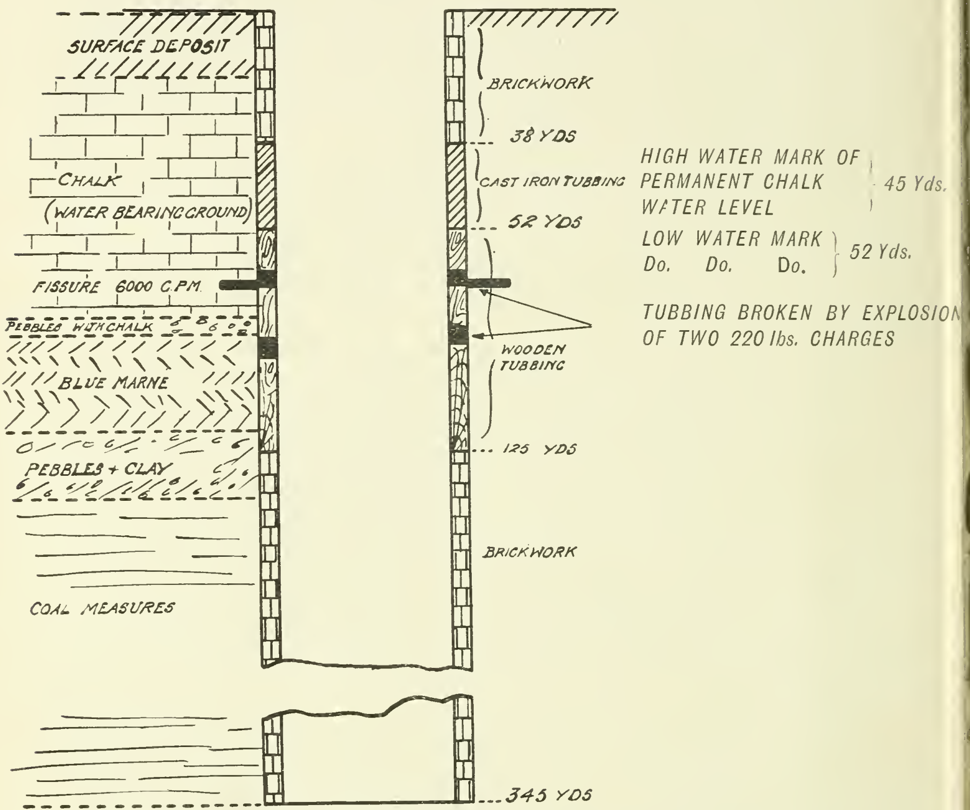



Plate 16.—Section of a Shaft, showing Tubbing destroyed by Explosion.

Plate No. 17 is a plan of the cementation holes, each hole having been bored vertically downwards to a depth of 125 yards, to ensure its reaching below the bottom of the water-bearing measures.

The diameter of the shaft was 16 ft., that of the outside circle of holes 84 ft., and the inside circle 67 ft.

The outside circle was injected and finished before the inside one was commenced.

The holes were treated in pairs, being situated on opposite

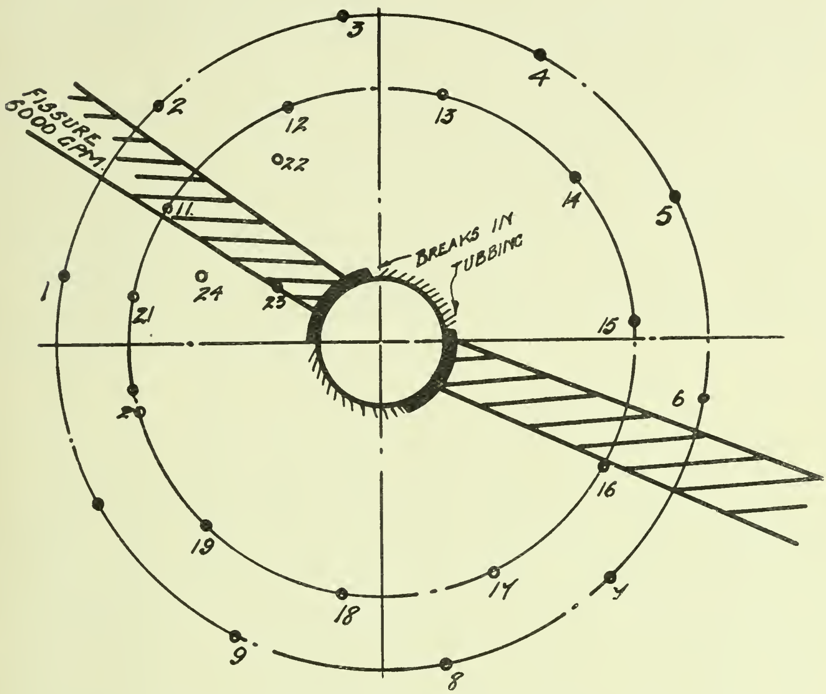



PLATE 17.—PLAN OF CEMENTATION HOLES FOR THE REPAIRING OF TUBBING DESTROYED BY EXPLOSION.

Diam. of shaft—16′. Diam. of outside ring of holes—84′. Diam. of inside ring of holes—67′. Depth of holes—360′. Depth of break in tubbing—190′.

sides of the shaft, the one being bored while the other was being injected.

An average of fourteen injections was found necessary in each hole, the injection commencing at a depth of 39 yards and being repeated about every 5 yards down, whenever water was being made in the hole. A total of 340 tons of cement was used for the outer holes and 101 tons for the inner ones.

When injecting, the pressure was not allowed to rise above 200 lb. per square inch, this being found ample for the type of ground under treatment.

One foreman and eleven men were employed on each shift, the total time taken for the completion of the work being just under three months.

The following particulars of cement injected are interesting, as on referring to Plate No. 17 they show clearly the amount of cement taken up by the fissure :

| Hole. | Cement injected. Tons. | Hole. | Cement injected. Tons. | Hole. | Cement injected. Tons. |
|---|---|---|---|---|---|
| 1 | 56 | 9 | 30 | 17 | 14½ |
| 2 | 51 | 10 | 34 | 18 | 8 |
| 3 | 19 | 11 | 8 | 19 | 5 |
| 4 | 19½ | 12 | 17½ | 20 | 10 |
| 5 | 18 | 13 | 6½ | 21 | 8 |
| 6 | 41 | 14 | 4 | 22 | 2½ |
| 7 | 40 | 15 | 8 | 23 | ¼ |
| 8 | 33 | 16 | 20 | 24 | 1½ |

On the water-level in the pit falling sufficiently to allow of the tubbing break being examined it was found that the flow of water had been completely sealed off, and in the place of the 6000 gallons per minute feeder which was visible in the shaft on its previous examination three and a half years before, only a small feeder of 25 gallons per minute remained; this latter was entirely sealed off after a few hours' further injection.

The successful treatment of the pit is one worthy of record, for with the exception of the fact that it was known that the tubbing had been badly broken at a vitally important part and that the shaft and neighbouring pits were completely flooded to a few yards from the surface, no information was

available that was of any assistance in the preparation of the scheme of treatment.

The majority of the pits were damaged by the Germans towards the end of 1915, and in consequence it had been found that at times the wooden tubbing had suffered considerably. In such cases the affected parts were treated by injection from the inside of the shaft.

As a result of the cementation of pit No. 11 and other pits in the neighbourhood it has been possible to start pumping operations on a large scale, and at the time of the examination of the pits the water-level was falling at the rate of 18 ins. per day; as further cementation is applied it is expected that this figure will be improved upon.

### 6. General Mining Work.

(*a*) *Drying of Shafts.*—Though drying of shafts may be termed a side line of cementation, yet there is no doubt that many shafts in this country have been greatly improved by the application of the process, and there are unquestionably many more in existence which could be treated with advantage.

Many of the older shafts in these coal-fields sunk through water-bearing strata have been lined with brick work, the water breaking through being collected by garlands and conveyed to lodge rooms.

Owing to the contraction and expansion caused in the lining by changes of temperature, leakages often occur which cannot be treated satisfactorily by wedging. By the boring of holes in suitable positions and injection of cement such shafts can be rendered perfectly dry. The benefit derived from the saving in pumping costs and the added comfort to men travelling in the shaft are matters well worthy of consideration.

Cementation can be further applied successfully in cases where tubbing plates have been broken, the removal of the defective plates thus being rendered unnecessary. An interesting case recently occurred where the sudden inrush of water through an old brick stopping in one of the tubbing plates situated about 130 yards from the surface necessitated the temporary closing down of the colliery, the quantity of water being estimated at 25,000 gallons per hour.

A cementation plant was despatched immediately, and 25½ tons of cement injected, reducing the water to 2500 gallons per hour. The process was continued, and by the following day the total inflow did not exceed 7 gallons per hour.

It is difficult to give any costs for drying of shafts, but the following example is fairly typical.

One hundred and fifty yards of lining in each of two shafts was in a poor condition, a quantity of water approximating to 2500 gallons per hour being made in each shaft. The conditions were consequently most unpleasant, and on account of the mine having a life of thirty years it was decided to apply cementation.

In two and a half months 97 per cent. of the water was shut off, the work being done at nights and during week-ends. The total cost amounted to £3600, or £12 per yard, being made up as follows:

| | £. | s. | d. |
|---|---|---|---|
| Labour and supervision . . | 2050 | 0 | 0 |
| Cement . . . . | 1150 | 0 | 0 |
| Materials . . . . | 400 | 0 | 0 |
| Total . . . | 3600 | 0 | 0 |

It is worthy of record that some forty shafts in England have been dried by cementation during the last few years.

(*b*) *Underground Dams.*—Owing to the speed with which

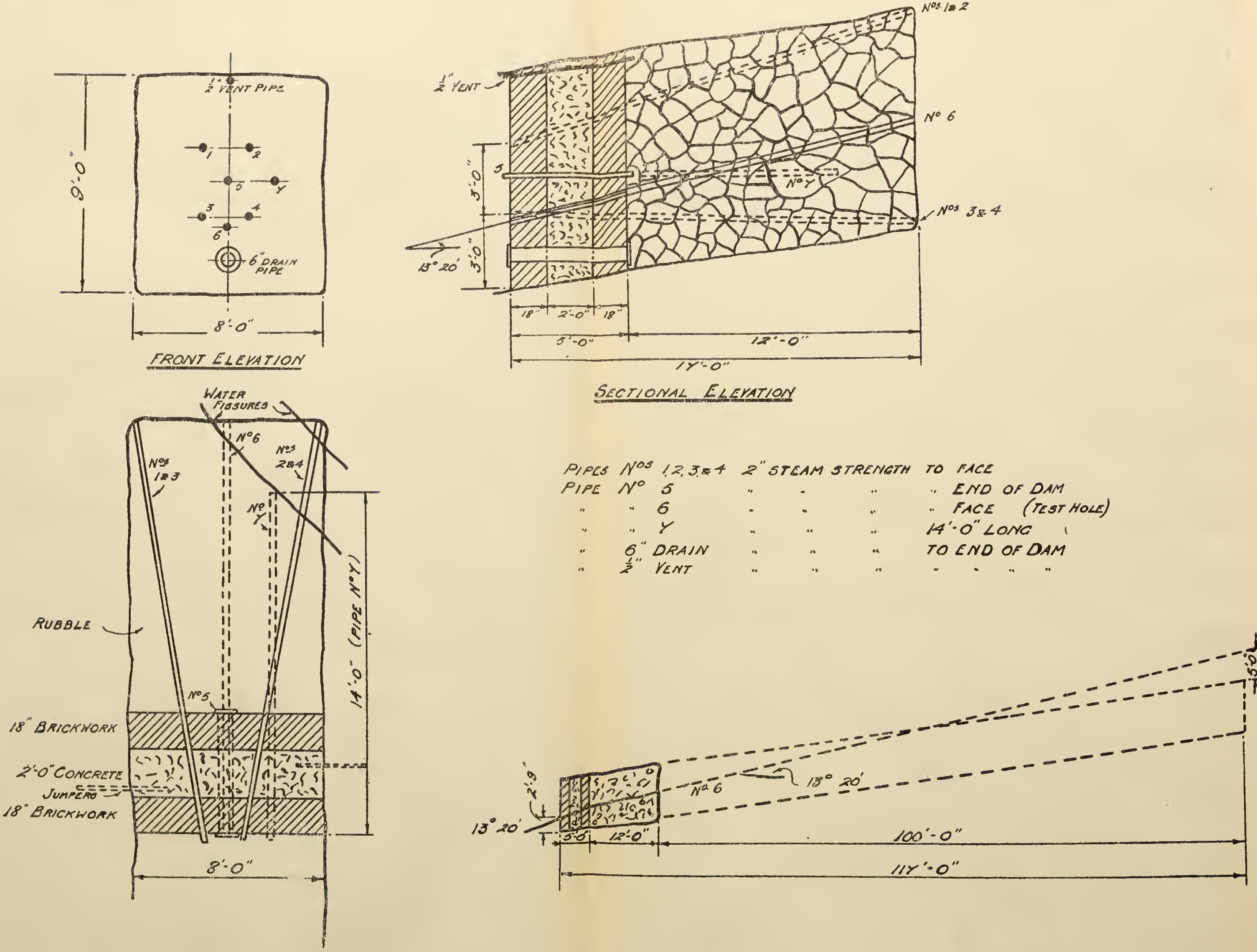
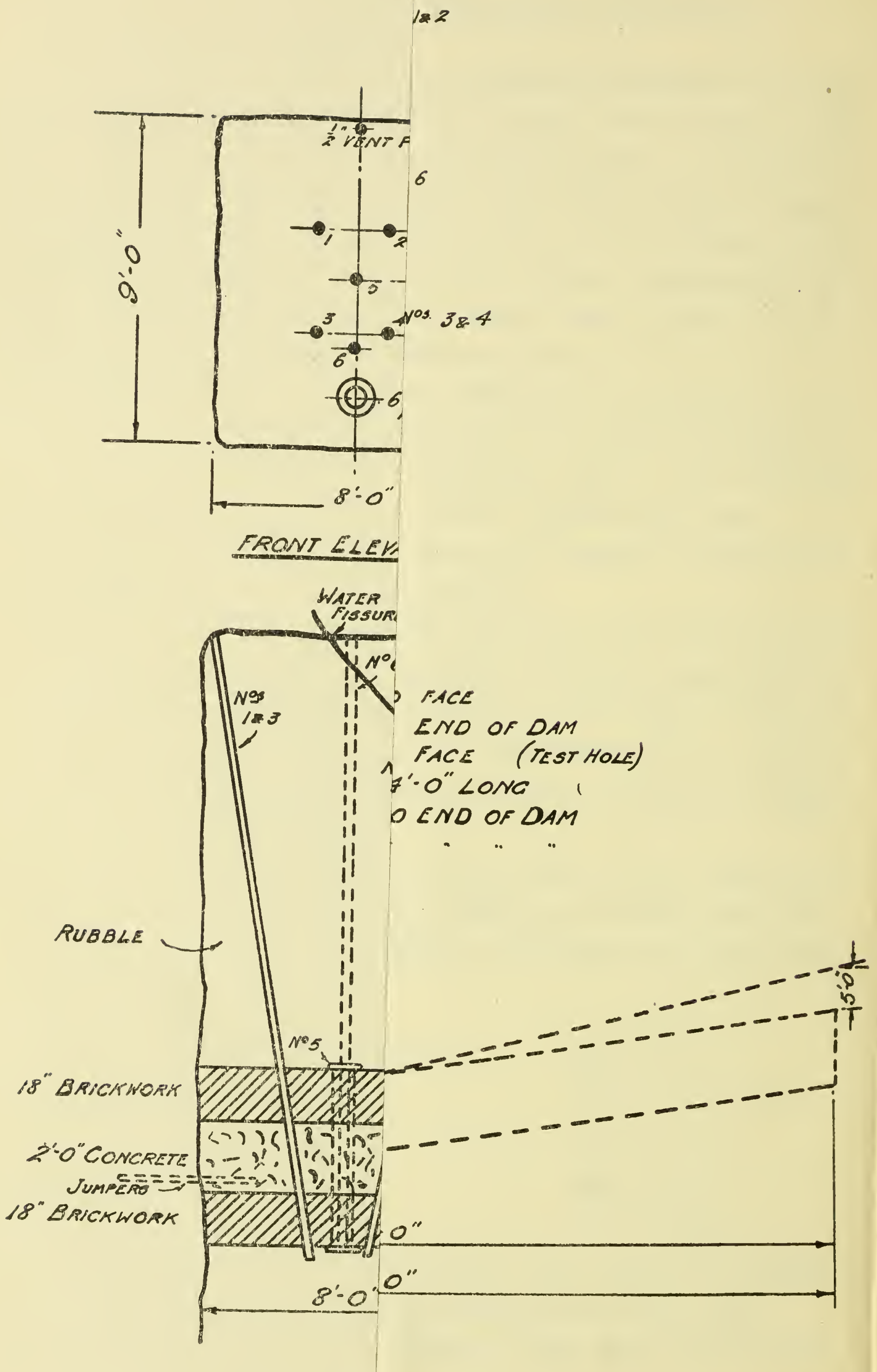



Plate 18.—Arrangement of Pipes in an Underground Dam in a Drive.


1 & 2
1" 2 VENT P
6
1
2
5
3
4
Nos. 3 & 4
6
6
9'-0"
8'-0"
FRONT ELEVA
WATER FISSURE
No
Nos 1 & 3
FACE
END OF DAM
FACE (TEST HOLE)
4'-0" LONG
END OF DAM
RUBBLE
No 5
18" BRICKWORK
2'-0" CONCRETE
JUMPERS
18" BRICKWORK
0"
8'-0"
0"
5'-0"

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underground dams have often to be constructed, there is a distinct likelihood of constructional weaknesses existing in same, these rapidly becoming apparent when subjected to water pressure. In such cases cementation can be used to great advantage in sealing up any small fissures.

Dams have lately been constructed in which cementation plays the chief part, the space between the face of the working and a strongly constructed brick wall being filled with rubble, pipes having been previously placed in position for the purposes of injection. On cement being injected a solid mass of concrete is formed, impervious to water.

Plate No. 18 shows details of such a dam, two heavily watered fissures having been met with while driving. Two 18-in. brick-work walls were constructed with concrete between, seven pipes for injection and a 6-in. drain pipe being placed as shown. At the conclusion of injection, hole No. 6 was bored for a further 100 ft. to prove the ground.

It is difficult to give figures for material and time, every case generally varying in some important detail. The following example, however, may be regarded as fairly typical of a case where it was necessary to strengthen an existing dam by constructing a second dam and concrete plug behind it, the space filled with rubble being 9 ft.

After forty hours' pumping this space was filled with cement, the pressure gauge reading rising rapidly.

The cement solution was made thinner and injection continued until the pressure had risen to 1700 lb. per sq. inch. At the conclusion of the injection it was found that the dam was water-tight.

The total time taken was 42 hours, and the amount of cement used 10 tons.

Plate 25 shows flashlight photos of some watery strata in an underground drive before and after the construction of a

circular dam for purposes of transport, details being given in Plate 19. A quantity of water equalling 1200 gallons per

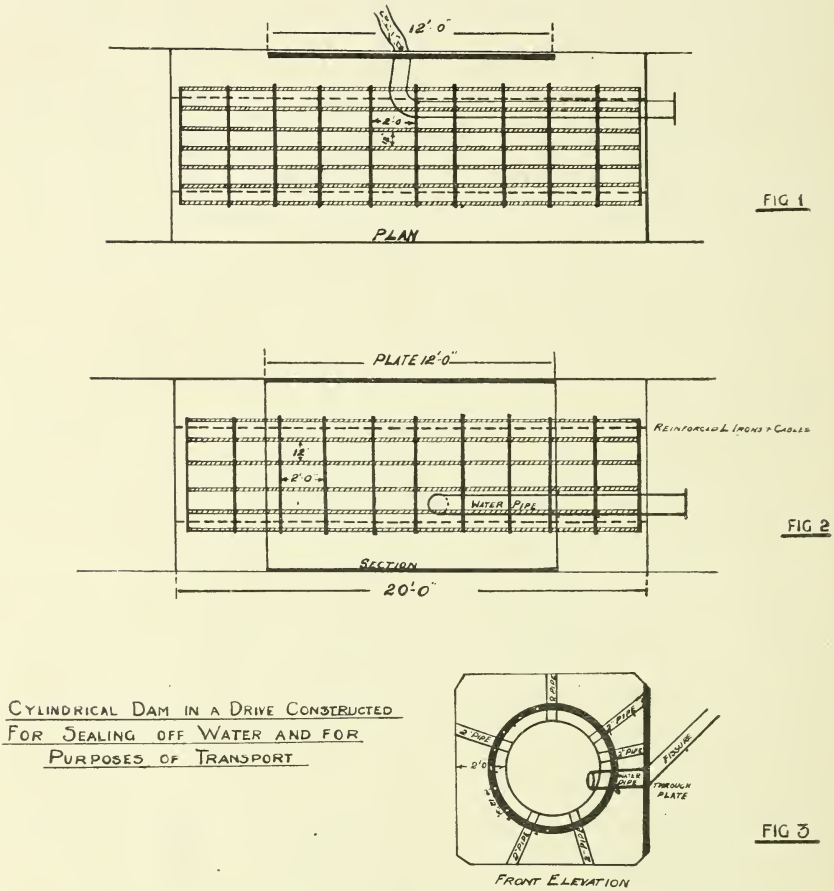



PLATE 19.

minute was successfully sealed off, 120 tons of concrete being built into place and injected with 4 tons cement at 4000 lb. per sq. inch pressure.

(*c*) *Underground Fires.*—The ordinary method of placing a dam and stoppage in an underground fire area is always open to the disadvantage that should a slight leakage of air

occur it is highly probable that the fire will break out again at some future time. By means of cement injections, however, such dams can be rendered absolutely air-tight, this method having often been adopted with success. On one occasion a fire had been burning in a main cross drift for a number of years, the arching having to be constantly renewed in consequence. Ordinary 2-in. diameter pipes were finally put into the roof between the steel girders, some of them penetrating through the timbers for a distance of 10 ft. to 12 ft. above the steel bars supporting the roof. On the injection of cement the many small fissures which showed up became blocked, and after a week's treatment the fire was extinguished.

What might have been in the nature of a disaster recently occurred about two-thirds of the way down the haulage shaft of a colliery, owing to an outbreak of fire in the old main coal seam worked out some twenty years previously. On the fire being discovered it was immediately decided to adopt cementation for the purpose of extinguishing it; in the space of eight days the fire was got completely under control, enabling work to be resumed. The usual procedure was adopted, a dam being built into the old heading and treated to render it air-tight. Several hundred tons of sand and water were finally injected into the fire zone through a pipe inserted in the dam, the mixture being run in from the surface.

## 7. Miscellaneous.

Cementation has been used in a variety of engineering problems besides those that come under the heading of mining. A few examples of such work will be of interest, as they will serve to show over how wide a field the process can be applied.

(*a*) *Cementation of Water-bearing Alluvial Deposits for Concrete Foundations.*—Work of a somewhat unusual character has lately been carried out in France, it being found possible

to inject gravel with cement under pressure from the surface, thus changing it into a species of concrete, suitable for heavy

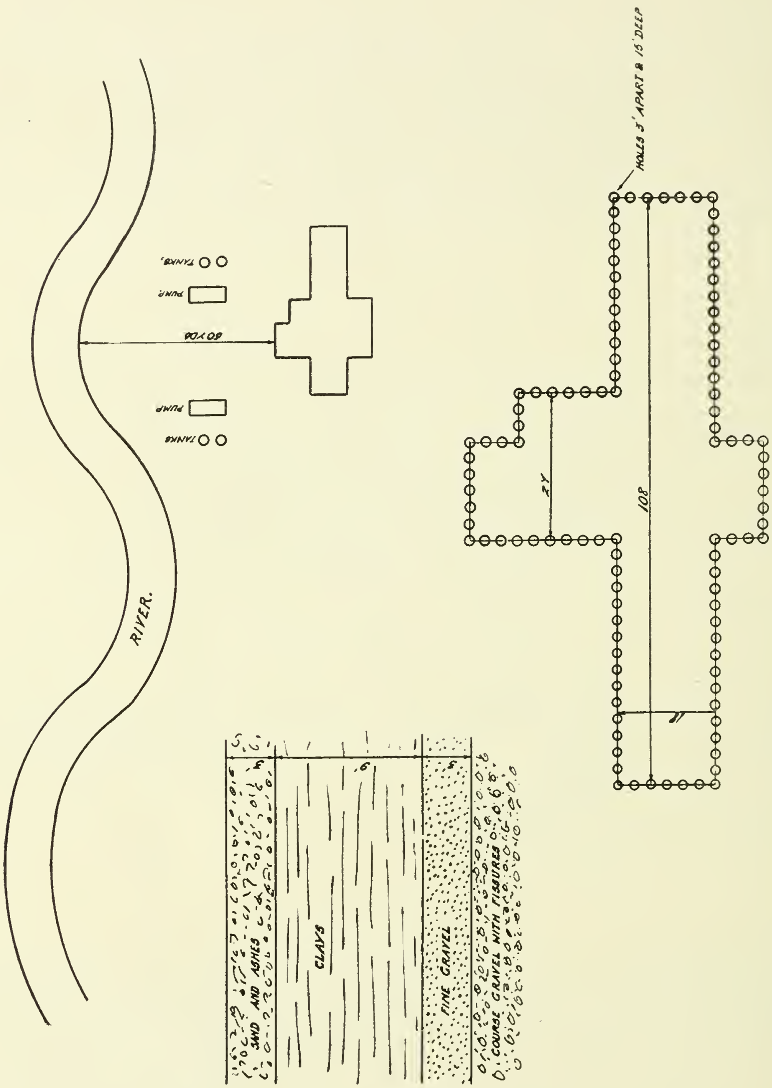



Plate 20.—Cementation of Water-bearing Alluvial Deposits for Concrete Foundations.

foundations. Plate No. 20 shows both the site chosen for the erection of some heavy rolling mills and a section of the ground.

Owing to the proximity of the river it was found most difficult to excavate down to the coarse gravel beds, a great quantity of water being met with. Two-inch pipes were accordingly driven in to a depth of $4\frac{1}{2}$ yards, 1 ton of cement being injected in each hole at a low pressure. On the completion of the injection the pipes were driven a further yard into the coarse gravel beds and allowed to stand for one day; on resumption of cementation cement was injected until the pressure rose to 250 lb. per sq. inch. The holes were spaced 1 yard apart and were placed just inside the line of excavation for the foundations.

For purposes of comparison two excavations were made for concrete columns, one without cementation and one with. In the former case, one month was necessary to complete the work, 400 gallons per minute having to be dealt with by pumping; in the latter four days were taken in treating the ground with $5\frac{1}{2}$ tons of cement, the water being reduced to 10 gallons per minute. On the ground being excavated a bed of cement 1 ft. thick was discovered, a further bed being proved in the coarse gravel deposits, and on a specimen of this latter ground being examined it was found to have been converted into concrete.

It was thus found possible to complete the work in a far shorter space of time and under more economical conditions than would otherwise have been the case.

(*b*) *Consolidation of the Foundations of a Surface Dam by Means of the Injection of a Number of Short Bore-holes.*—This work was recently carried out in Africa, and consisted in solidifying a laminated and fissured bed of ironstone rock overlaying solid dolomite. Under ordinary conditions it would have been necessary to excavate a large quantity of the pervious rock down to the water-tight rock, but this was rendered unnecessary by drilling a series of 80 holes and treating them thoroughly by cementation. About 300 tons

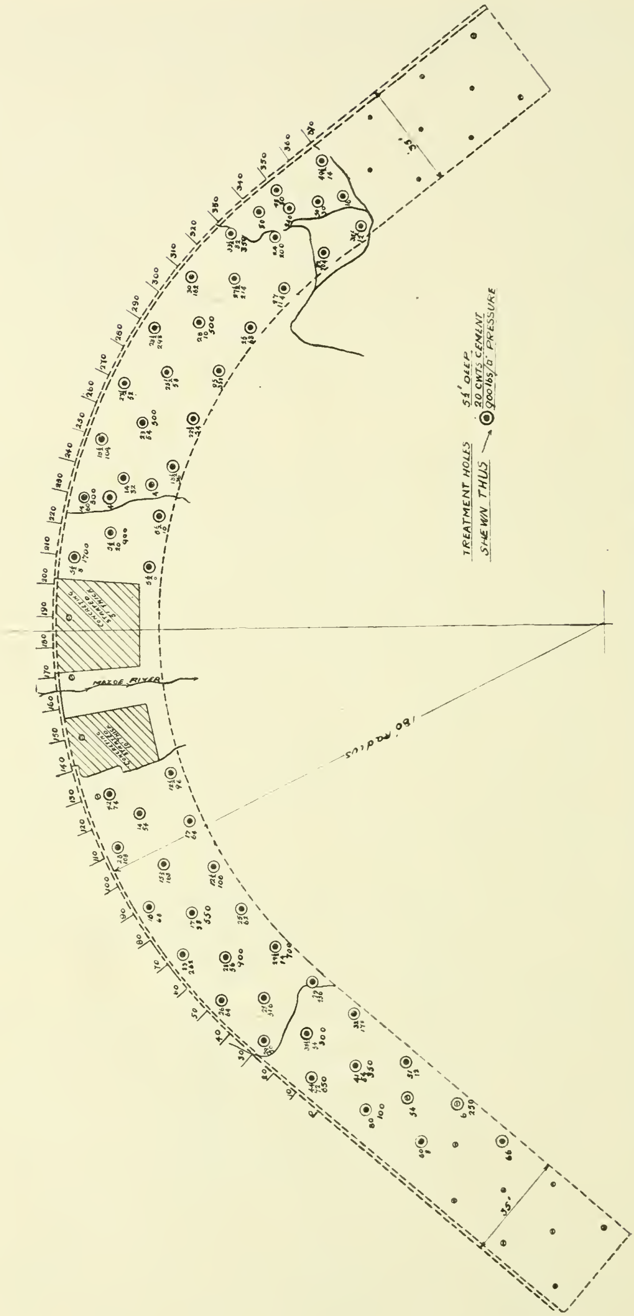



PLATE 21.—PLAN SHOWING THE METHOD OF CONSOLIDATING THE FOUNDATIONS OF A SURFACE DAM BY MEANS OF THE CEMENTATION OF NUMEROUS SHORT BORE-HOLES.

of cement were injected in this way at pressures varying up to 1700 lb. per sq. inch.

Plate No. 21 shows a plan of some of the bore-holes with particulars of injection, the actual construction of the dam itself being shown in Plate No. 22. The solidification of the foundations of the dam proved most satisfactory and permitted the building of a dam wall 105 ft. high, 380 ft. long, 33 ft. wide at the base, and 10 ft. wide at the top.

(*c*) *Cementation of the Foundations and Floor of a Pumping Station.*—In this case it was found that the main engine foundations and engine-house walls were subject to heavy vibrations and movement, considerable disturbance to defective concrete foundation work having apparently been caused by earth tremors somewhat common in that neighbourhood. Bore-holes were drilled in and around the foundation, and after the injection of 70 tons of cement a complete state of rigidity was imparted.

(*d*) *Prevention of 'Creep' and 'Thrust' at a Shaft Bottom.*—An example of this kind of work occurred a short while ago in a colliery where, owing to the presence of water at the shaft bottom, the surrounding shale had been caused to swell, affecting in turn the roof of the arched shaft siding, which showed signs of serious collapse for a considerable distance.

In spite of the concrete lining being one yard thick and supported by girders, the strain was so great that a shield of wooden lagging had had to be constructed as a safeguard against the pieces of concrete which were continually flying off.

As it was difficult to tell at the commencement of the work where the water actually was, three holes were bored vertically upwards for 120 ft. at a distance of 20 yards from one another without, however, tapping any water. Holes were next bored vertically down, water being met with at a distance

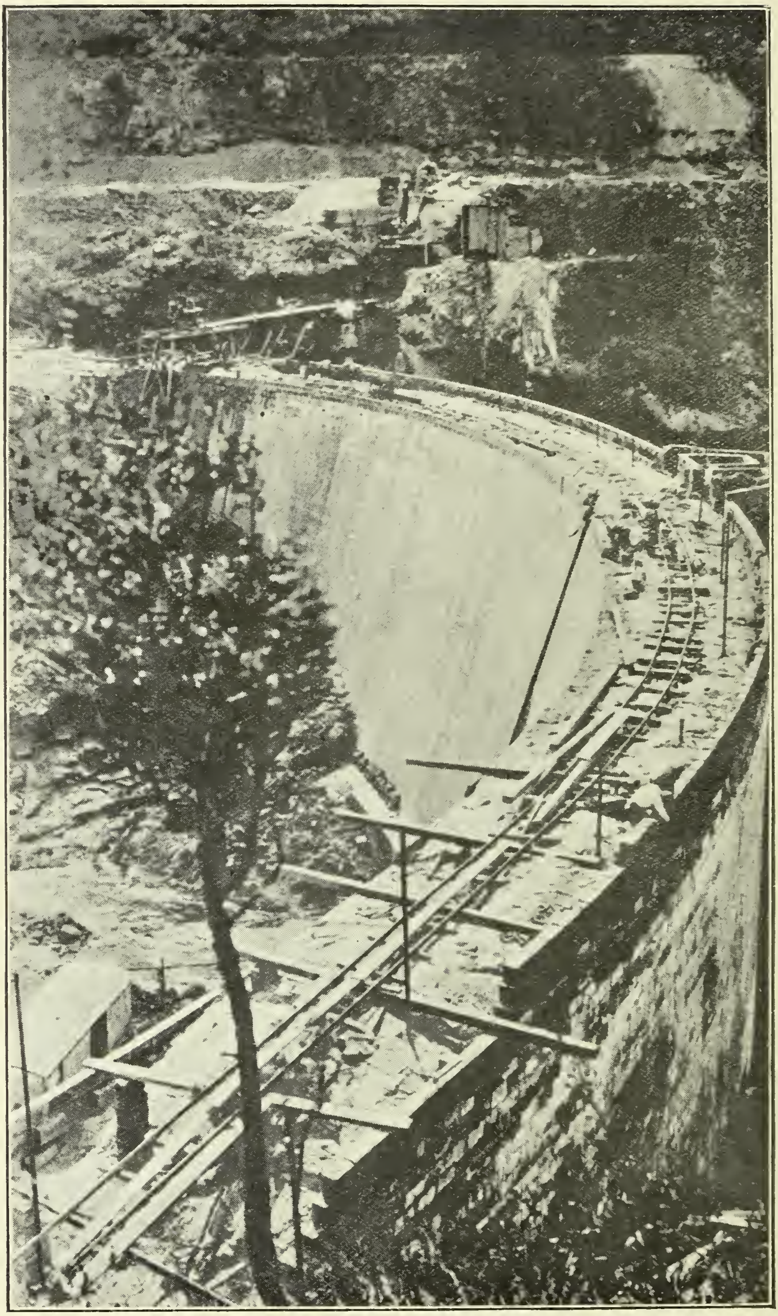
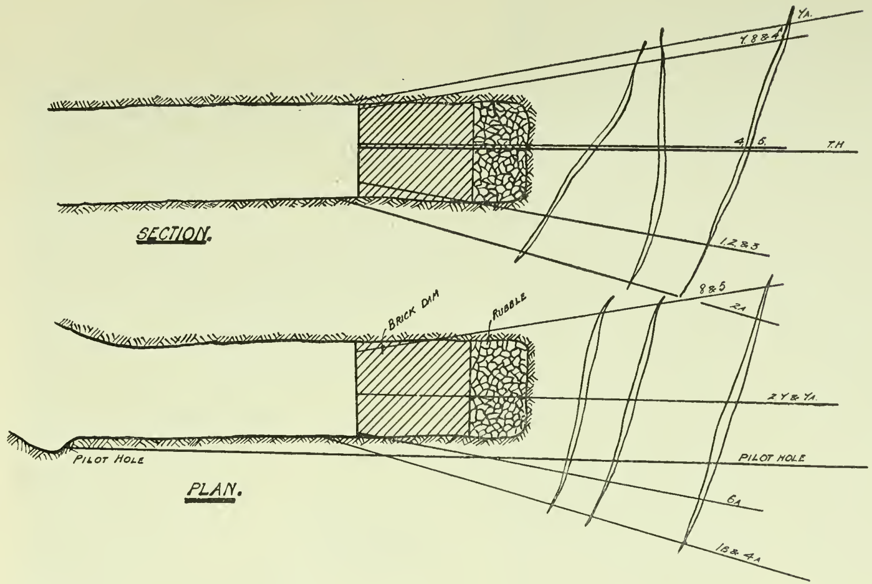
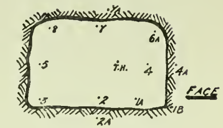


Plate 22.—Construction of a Surface Dam after consolidation of Foundations by Cementation.




| Hole No. | Depth | Fissures at Face — Galls p. min | Total Galls p.m. | Cement injected Tons | Cwts | Pressure injected to |
|---|---|---|---|---|---|---|
| 1 | 20 | 30'/30 | 30 | 1 | 12 | 2000 lbs |
| 1B | 47½' | 20'/55  23'/10  36'/3  43'/30 | 98 | 1 | 15 | 1600 |
| 2 | 70 | 10'/15  28'/40  34/30  58/4 | 109 | 1 | 12 | 3000 |
| 2A^T | 80 | 43'/8 | 6 | | 8 | 800 |
| 3 | 51 | 20'/23  43'/3  49'/73 | 45 | | 13 | 2700 |
| 4 | M H | | | | 12 | 2000 |
| 4A | 63½ | 40'/7  60'/7 | 2 | | 11 | 2200 |
| 5 | 55 | 40'/3 | 5 | | 2 | 1800 |
| 6A | 66 | 15'/60  28'/35  46'/3 | 100 | 4 | 18 | 2000 |
| 7 | 53½ | 20'/40  30'/30  51'/7 | 97 | 2 | 2 | 1700 |
| 7A^T | 72½ | 66½/2 | 2 | | 5 | 2200 |
| 8 | 51 | 21'/40  34'/13  50/13 | 70 | 1 | 12 | 2000 |
| Pilot | 110 | 63/13  80/13 | 50 | | | |

PLATE 23.

Plate 23.—Plan showing the Cementation of a Drive in Fissured Ground.

of 12 ft. Three series of holes were then bored: Series 1 straight down, Series 2 at a dip of 45 degrees, and Series 3 horizontally, each hole being approximately 3 ft. from its neighbour. The holes of Series 1 were treated first, followed by Series 2, and finally by Series 3.

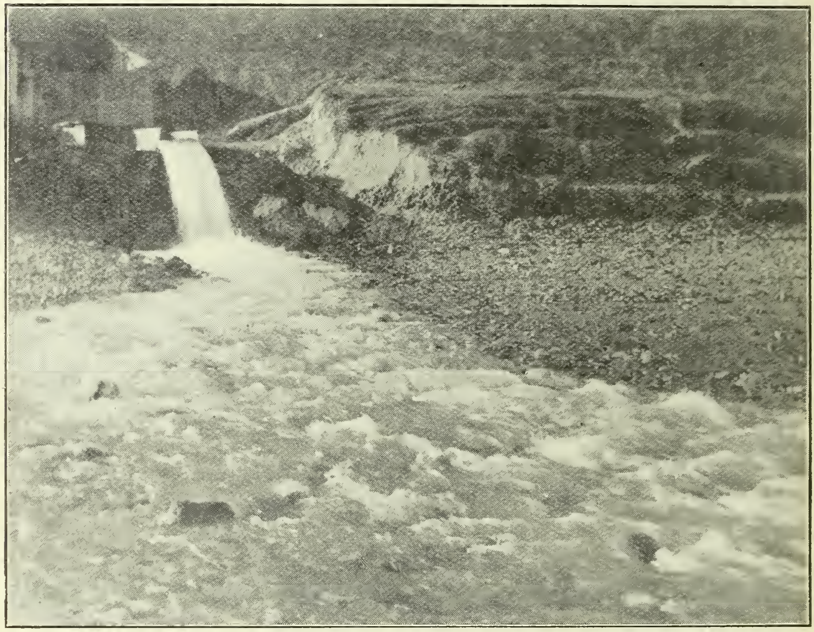
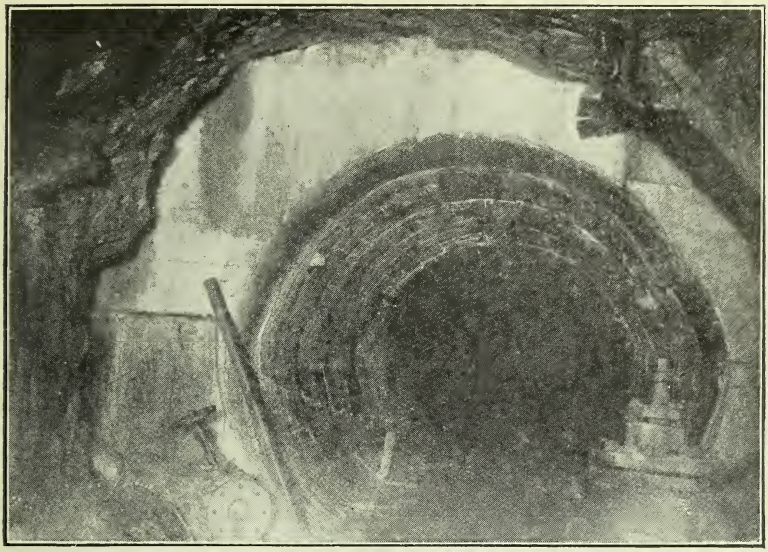


Plate 24.—Water from Shaft Fissures subsequently sealed by Cementation.

The whole affected area was treated in this manner, some 60 tons of cement being injected at a maximum pressure of 300 lb. per sq. inch.

At the conclusion of the injection the key of the arch was replaced by a fresh one, further cement being injected through holes in the roof to render it as tight as possible. Although only two months were taken over the work, the whole siding was consolidated, and no further treatment or repair work has been necessary.



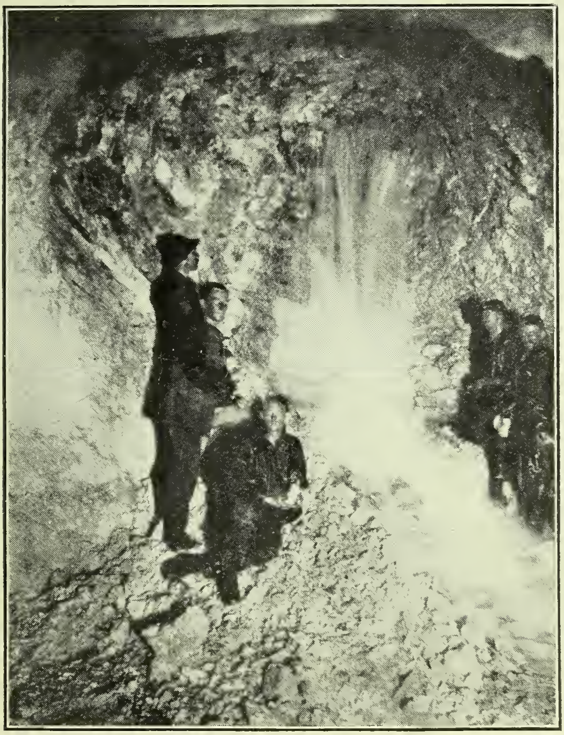


**Plate** 25.—Water-bearing Ground before and after the Construction of a Circular Dam for Purposes of Transport.

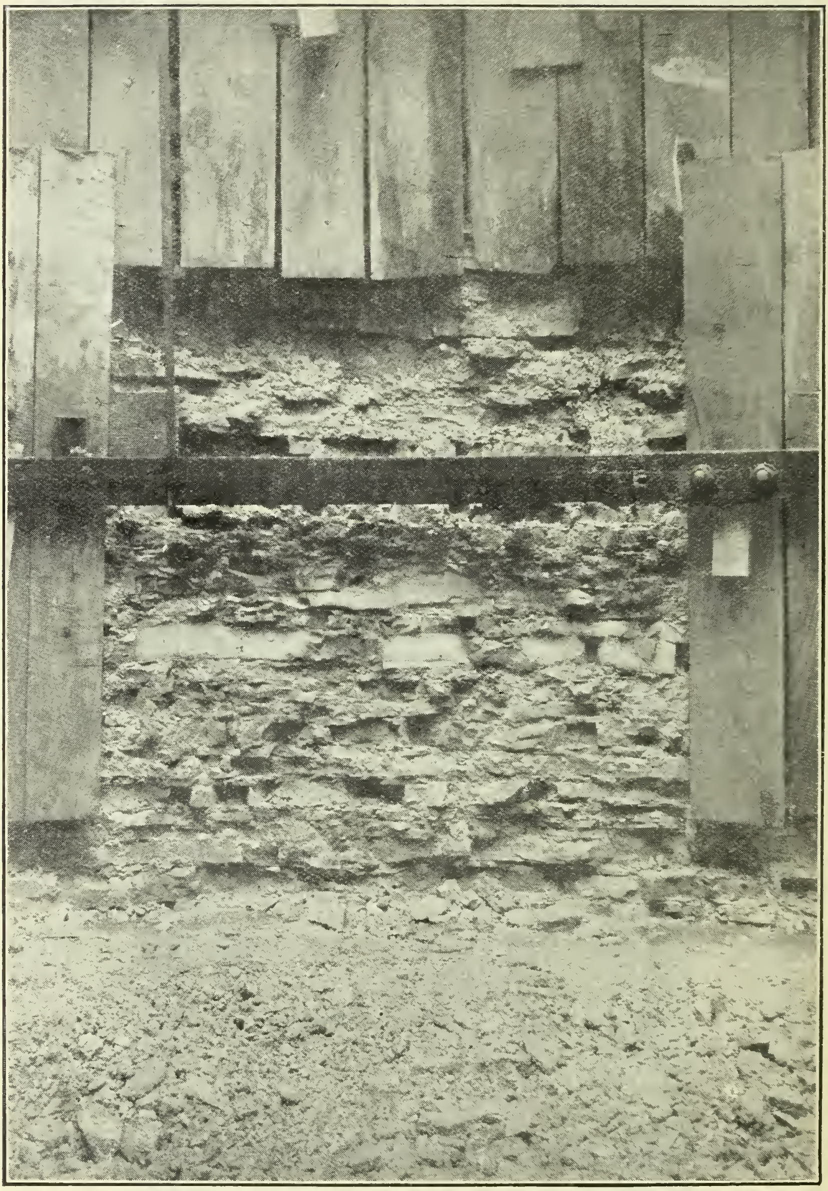


PLATE 26.—THE CEMENTATION OF A FISSURE IN A SHAFT.

Plate No. 23 shows the cementation of a drive in fissured ground, the end of the drive being of such a shattered nature that it was necessary to construct a dam and treat the virgin ground by means of bore-holes through pipes placed in the dam itself. On referring to the plate full particulars will be found of number of holes, cement injected, and water sealed off.

Plate No. 24 shows a quantity of water of over one million gallons per hour encountered during the sinking of two shafts—this was subsequently entirely sealed off by cementation.

Plate No. 26 is a photo of a fissure in a shaft completely filled by cement.

In conclusion it is hoped that the paper may have helped to show how important a part cementation is playing in modern engineering problems.

Though the improved process is still more or less in its infancy, sufficient confidence has been placed in it to warrant the formation of a powerful London company under the name of the François Cementation Company, Limited.

Perhaps it is not an impossible flight of fancy to imagine at some future date the much talked of Channel Tunnel being constructed with the aid of the Cementation Process.

## The Discussion.

Opening the discussion, the PRESIDENT said the author had told them that the cementation process was comparatively new, being first experimented with in England in 1911. He (the President) had little doubt that in future the process would be applied to all shaft sinking, especially in strata containing large volumes of water. They were all aware that many shaft sinkings in the South Wales coalfield had involved enormous sums owing to water, which had to be pumped out The President.

The President. and tubbed back, and this cementation process seemed destined to effect substantial economy in that direction, especially when it was resorted to before the watery strata had been struck.

The Secretary. The SECRETARY read a contribution to the discussion from Mr. E. L. Hann, who expressed regret at his inability to be present at the meeting.

Mr. E. L. Hann. Mr. E. L. HANN wrote: The subject of the paper is of the greatest interest to mining engineers, and the system described is likely to become of greater importance as the benefits to be derived from it become more widely known.

The very large quantities of water now being pumped both in the Pennant rock and in the shales could in all probability have been sealed off by means of the application of cement, and thus have saved large additional capital expenditure required, in addition to the delay in sinking as well as the heavy cost of continuous pumping. One of the important points emphasised by Mr. Ball, viz., the proving of the ground by means of a borehole before sinking, is one which has not generally been adopted in this district in the same way as has been done in other coalfields, especially on the Continent; but where there is any reasonable probability of water being met, it is a form of insurance which ought to be taken, since it will be realised from the description given in the paper that the construction of a concrete plug at the pit bottom, which is almost always necessary when water has once been met and before cementation can take place, is an extremely expensive operation. One of the objections raised against cementation during sinking is the delay, and consequently very heavy extra cost, due to stopping the actual sinking work during boring and cementation. It is obvious that, in order to carry out a really cheap sinking, it is necessary that the work should be done rapidly and no delays occur. Consequently, it is advisable that the boring and cementation should be done in as long lengths as is possible, and in most cases it would be

found that rather than interrupt the sinking and consequently have to employ the sinkers on day work on the surface, it is better to put up with the increased cost of boring to a comparatively great depth, so that when sinking does start, it can be carried out with as few interruptions as possible. Mr. E. L. Hann.

It would be of interest if the author would state whether a fast, medium, or slow-setting cement is preferable.

The account of the sinking in porous ground by means of silicate of soda and sulphate of alumina is extremely interesting, though the theory that the gelatinous nature of the silicate of alumina causes lubrication and enables cement to be forced where it otherwise would not be possible, is somewhat difficult to follow. One can hardly understand how a particle of cement, which cannot be forced into an opening under 2000 lb. pressure, can be helped by the lubricating quality of any material. It appears probable that whilst the finest particle of cement could not enter the pores of the ground, it is quite possible to inject two liquids, which on meeting in the pores of the ground form a precipitate and consequently block the passage of water. If the difficulty was merely a question of lubrication, it is to be presumed that there are many other substances, having in themselves lubricating properties, which might be used and pumped into the ground.

The system of lining a shaft with reinforced concrete is one which is likely to be almost universally adopted, especially where water-tight brickwork and cast-iron tubbing have been previously used, and when it is considered that the reinforcement and back plates act as a very satisfactory form of timbering, it will be found that the cost of this form of lining is quite reasonable, whilst it is certainly much more reliable than water-tight brickwork.

Again, it is found in a great many of the deeper shafts in South Wales that great trouble is experienced where the shaft passes through coal seams having soft fireclay floors. Under

Mr. E. L. Hann.

such circumstances, there is no doubt that reinforced lining will completely avoid any trouble from 'squeeze.' However, in the ordinary Pennant rock and harder zones of the coal measures, it will probably be found that reinforcement is not necessary and that the shaft can be lined with plain concrete at a somewhat cheaper price and certainly more rapidly than with brickwork.

It will be extremely interesting if the author can give some figures stating what has been the cost of sinking and cementing through water-bearing zones, under various conditions.

Mr. W. Forster Brown.

Mr. W. Forster Brown (President-Elect) said he had had some experience of cementation in a case where the pumping method was abandoned after all the pumps were ready, and he must say the abandonment in favour of cementation was never regretted. The cementation process, however, took a long time to accomplish its work—a point to which Mr. E. L. Hann had referred. He asked Major Ball which system, whether long or short lengths, of cementation he would recommend to make the best progress where two shafts were being sunk and the ground was favourable. In the case which he had mentioned the holes were long, and the point occurred to him whether better progress would have been made with shorter lengths, assuming they had been able to get over the difficulty of keeping the sinkers employed by moving them from one shaft to another. With regard to drifts, the author said the bottom holes were first cemented, and that this helped in dealing with the other boreholes. He presumed that in this case the water was below the drift and not above it. Presumably Major Ball did not mean they should always cement the bottom holes first in a drift. Another point upon which he would like the author's opinion was the cementation of underground gobs as a practical proposition. As was well known, they had great difficulty in maintaining some of their underground roads at a reasonable cost, and it had often

occurred to him that this might perhaps be materially lessened if they cemented the gob for certain distances on each side of the main road. Of course, this would not be a case of providing against water from fissures, but of putting water into ground that perhaps had had no water in it before, and the effect upon the road might be unfavourable, because they knew that if they had a coal pillar on each side of a main road when working on the long-wall method, the chances were that the road would gutter up in the roof and they had trouble. To put aside for the moment the question of cost, it would be interesting to know from the author of the paper whether cementing, say, 20 yards on each side of a main underground road had ever been tried, and, if so, what was the effect on the maintenance of the road. **Mr. W. Forster Brown.**

Mr. W. O'Connor said the author had told them of the early failure of the process of cementation when applied to the New Red Sandstone, which was a very porous and friable rock. He asked the author whether there were any other causes of failure. No new process or invention suffered in reputation by those responsible for it informing them of early failures and the causes thereof. One frequently learnt more from failures than successes. With regard to sinking in porous ground, one had difficulty in understanding how the injection of silicate of soda and sulphate of alumina had assisted the cement to get farther into the ground. They had usually viewed sulphate of alumina as being more calculated to clog. The author told them that the injection of cement under high pressure caused the cement to set more rapidly. What was the explanation of this? Did high pressure contribute to a speedier crystallisation of the silicate of soda and sulphate of alumina? One of the limitations of the cementation process appeared to be this: while the process might be quite successful in shutting out water from shafts, he doubted whether in the Pennant strata with which they **Mr. W. O'Connor.**

Mr. W. O'Connor.

were familiar in South Wales it was going to benefit collieries as a whole, because their experience showed them they would bring down water in any case, and it became a question whether the saving in pumping and avoiding delays in sinking would counterbalance the cost of cementation during sinking. Major Ball had shown them how the cementation process had been used for consolidating alluvial ground, and had instanced the case of the foundations for French rolling mills. Would the process be similarly successful in consolidating alluvial ground in the Pennant rock, and how many boreholes would be required in the river bed in order to ensure watertight strata beneath the level ?

Mr. W. Cleaver.

Mr. W. Cleaver said he did not quite see the necessity of the steel lining for shafts described by the author, seeing that the consolidating effect of cementation was fully established. It appeared to him that the setting of the concrete would be much more effective if the inner steel lining was omitted. As to cementation in gravel, he would like to know if the gravel, after cementation, had proved sufficiently solid to support average pressure without excavating at all ?

Mr. James Elce.

Mr. James Elce stated that overlying some seams of coal there was an intervening bind or clift measuring anything from 7 to 13 feet, and lying in between the coal and hard rock; and frequently when the intervening bind or clift between the coal and rock broke away, there were flushes of water from the overlying rock. He would like to know if cementation had been tried to consolidate this bind or clift between coal and rock in principal headings to prevent these flushes of water.

The President.

The President said Mr. O'Connor had spoken of water coming into the workings from the Pennant. Did Major Ball recommend the adoption of cementation where seams were worked in the Pennant rock or the lower steam-coal measures below the Pennant.

Major BALL: Both, Mr. President.

Major Ball.

The President

The PRESIDENT said he did not know whether it was possible to cut off by cementation the very heavy streams of water in workings in the Pennant. He knew of a seam in the Swansea district where the whole of the strata above it to the surface was Pennant rock, and a considerable quantity of water found its way from the surface into the workings, and where a fault was met with it was a very costly matter indeed. With regard to the steam-coal measures, he was not aware of any case in which Pennant water had passed through the shales into those measures. Perhaps Mr. O'Connor knew of such a case.

Mr. W. O'Connor.

Mr. W. O'CONNOR said he thought there were such cases.

Mr. F. E. Jacob.

Mr. F. E. JACOB presumed that the cementation process could be successfully applied to cases in which shafts had been sunk to the steam coal measures, through seams that have already been worked out, and giving off heavy feeders of water, and thus eliminate the costly pumping charges.

Mr. Forster Brown.

Mr. FORSTER BROWN asked if the costs given in the paper were pre-war costs.

Replying on the discussion, Major BALL said:—

Major Ball.

In reply to Mr. Edmund L. Hann, his assumption that the chemical precipitate, formed by the mixture of sodium silicate and aluminium sulphate in the pores of the ground, acts as a block to the passage of the water is in accordance with present accepted theories.

The aluminium silicate formed is of a complex nature and passes through various gelatinous stages, finally forming a hard, compact, and impervious solid. The action of the precipitate is apparently two-fold. In its gelatinous stages it is used as a lubricant and temporary cementing agent for the loose material in the fissures, thus allowing cement injections to follow with greater ease than would otherwise have been the case. This 'stage' is made use of in the 'cement holes.'

Major Ball. In the 'product holes' the silicate is used as the cementing agent, followed by a small quantity of cement to seal off any fissures not blocked by the product injection. There are other chemicals which can be used for the purpose described, but their use is not commercially economical.

In all cementation work a special finely-ground, quick-setting cement is used.

It is extremely difficult to give any actual costs of sinking by cementation through water-bearing zones, as in practically every case in which the process has been used in England the sinking had already entered the water-bearing strata before the aid of cementation was invoked, thus necessitating a considerable amount of work which would otherwise have been unnecessary. There are at present several shafts being sunk in which cementation has been used from the beginning; when these are finished it will be possible to obtain the figures desired.

With reference to the points raised by Mr. W. Forster Brown, it is more economical in the case of two shafts being sunk together to have the 'lengths' as long as possible and so arrange the working conditions that one shaft is being cemented while the other is being sunk, and *vice versâ.*

In 'drifting,' the choice of the first holes to be treated depends entirely upon local conditions.

The treatment of underground gobs by cementation has not been attempted up to the present. Old workings met with while sinking have been dealt with by means of rotary pumps injecting quantities of ashes, shingle, and cement to fill up the cavities, the mass being consolidated by means of cement injections with high-pressure cementation pumps. A modification of this process can doubtless be successfully adopted in the case under discussion.

The cementation of the ground on either side of the main road has not so far been tried.

The figures of cost in the paper refer to the 'drying' of a shaft nine months ago. **Major Ball.**

Mr. W. O'Connor, F.G.S., has raised, among other points, the question of past failures in connection with the cementation process. The only temporary failure encountered, as has been previously mentioned, was in the case of the first sinking essayed in the New Red Sandstone. Practically every job differs in some respect from another, and what may at first sight appear to be a failure invariably affords an acquisition of knowledge which leads to a speedy and economical solution of later problems of a similar nature. In such a class may be cited the cementation of the bed of sand above the coal measures in a colliery in Kent.

As to the use of high pressures in the injection of cement, these are necessary firstly to overcome the pressure of water in the rock fissures, secondly to ensure the cement penetrating into the most minute cracks, and thirdly to squeeze out the excess water in the cement, until ultimately the fissure is completely filled with cement with just sufficient water to produce the best conditions for setting.

The answer to the question whether the saving in pumping and avoiding of delays in sinking would counterbalance the cost of cementation is most certainly in the affirmative, for not only is the sinking rendered dry and safe, but the absence of worry over pumping plants and problems of a like nature is a point not unworthy of consideration.

As to the cementation of river beds, no work of this nature has been carried out in England, the only example of this type of work being that described in the paper.

Mr. W. Cleaver, M.Inst.C.E. It has been found that in some cases of sinking by cementation it is not economical entirely to shut off all the water until the concrete wall has been built up and injected. The back sheeting is inserted to prevent

Major Ball. the water mixing with the concrete and washing away the cement and sand. The space behind the back sheets is ultimately filled up with fine concrete and intimate contact with the ground established by cement injections.

As to the question put by Mr. Elce, the process of cementation has not been tried in such a case as that cited.

In the case referred to by Mr. F. E. Jacob there is but little doubt that cementation can be applied with success whenever the source of water has been traced. Large quantities of water are often met with in shafts, necessitating heavy pumping charges and rendering conditions most uncomfortable. In such cases it is an easy matter to seal off the water by means of cement injections through boreholes, whose position naturally depends upon the local conditions.

Since the reading of the paper several enquiries have been received as to the possibility of some form of cementation being applied to the Severn Tunnel. It is the author's opinion that this unquestionably could be done with great advantage, for not only might a considerable saving be effected in the large sum of money which is annually incurred in the pumping of the water which leaks into the tunnel, but a saving could also be experienced in the general repair work which is necessary to the walls and roof.

In conclusion, the author would like to express his appreciation of the keen interest evinced by Members in the paper.

The President. The PRESIDENT said he was sorry he could not adjourn the discussion on account of the number of papers they had on hand, because Major Ball's paper would certainly bear further consideration. It dealt with a highly important subject. He proposed a hearty vote of thanks to the author. (Applause.)

Major Ball. Major BALL briefly acknowledged the vote, and the meeting closed.

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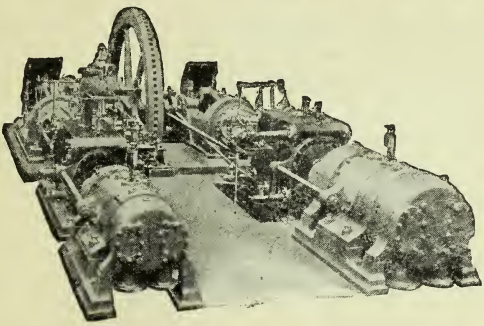



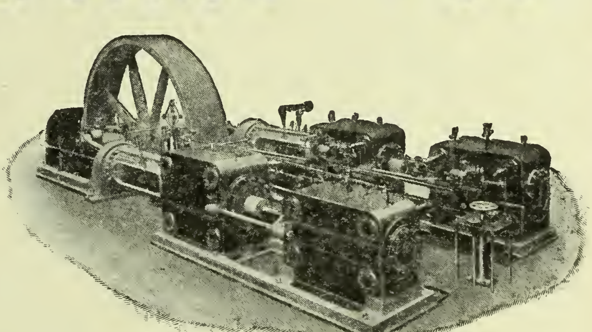

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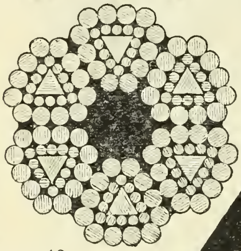

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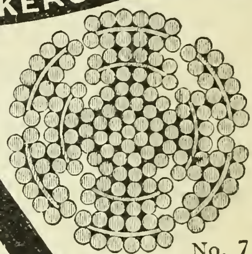

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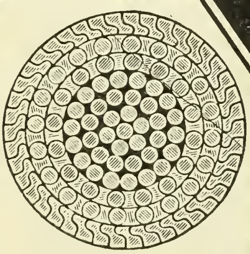

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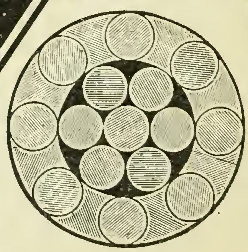

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